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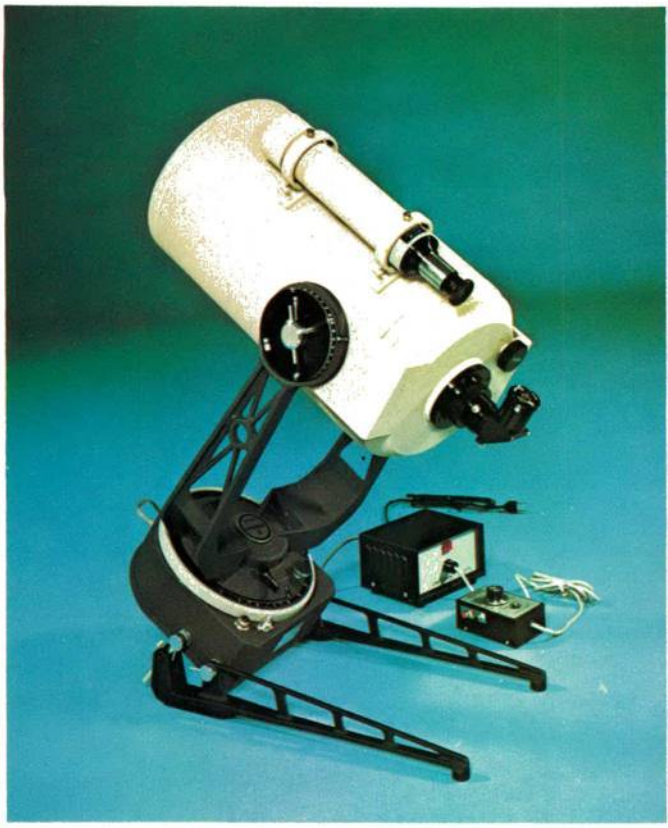

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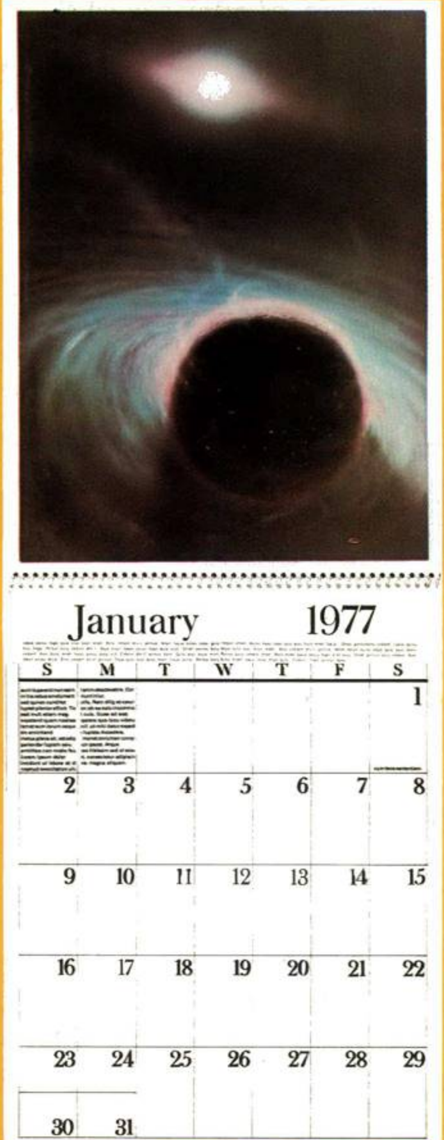
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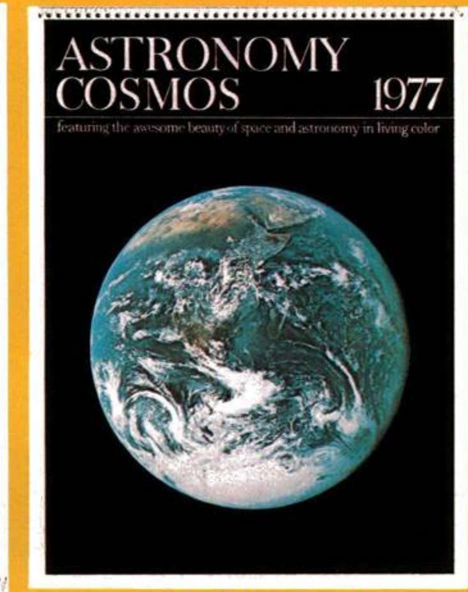
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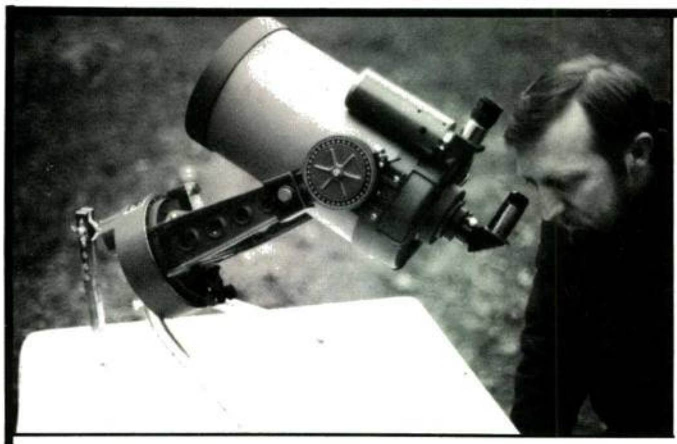

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February 1977 Vol. 5, No. 2

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Cover

Our cover depicts an incredibly rare encounter: A miniblack hole barely nicks the surface of a one mile diameter asteroid, causing a blast akin to a nuclear explosion. The actual collision lasts only 1/1,000,000 second; the black hole tears a few kilograms of rock from the asteroid surface. This matter becomes superheated as it enters the intense gravitational field near the miniblack hole, and then releases an intense burst of heat, light, x-rays and gamma rays. The side of the asteroid near the hole melts or vaporizes in a violent explosion (direct hit would have destroyed the asteroid). Miniblack holes are featured in this month's Stellar Frontiers. Our lead articles take you to the edge of our solar system — to Uranus, Neptune and tiny icy Pluto — and to the limit of man's knowledge of these remote objects. ASTRONOMY also brings you observing hints for Saturn's opposition, along with pictures of the Australian solar eclipse and the first of a two part article on cold cameras. Painting by Mark Paternostro.

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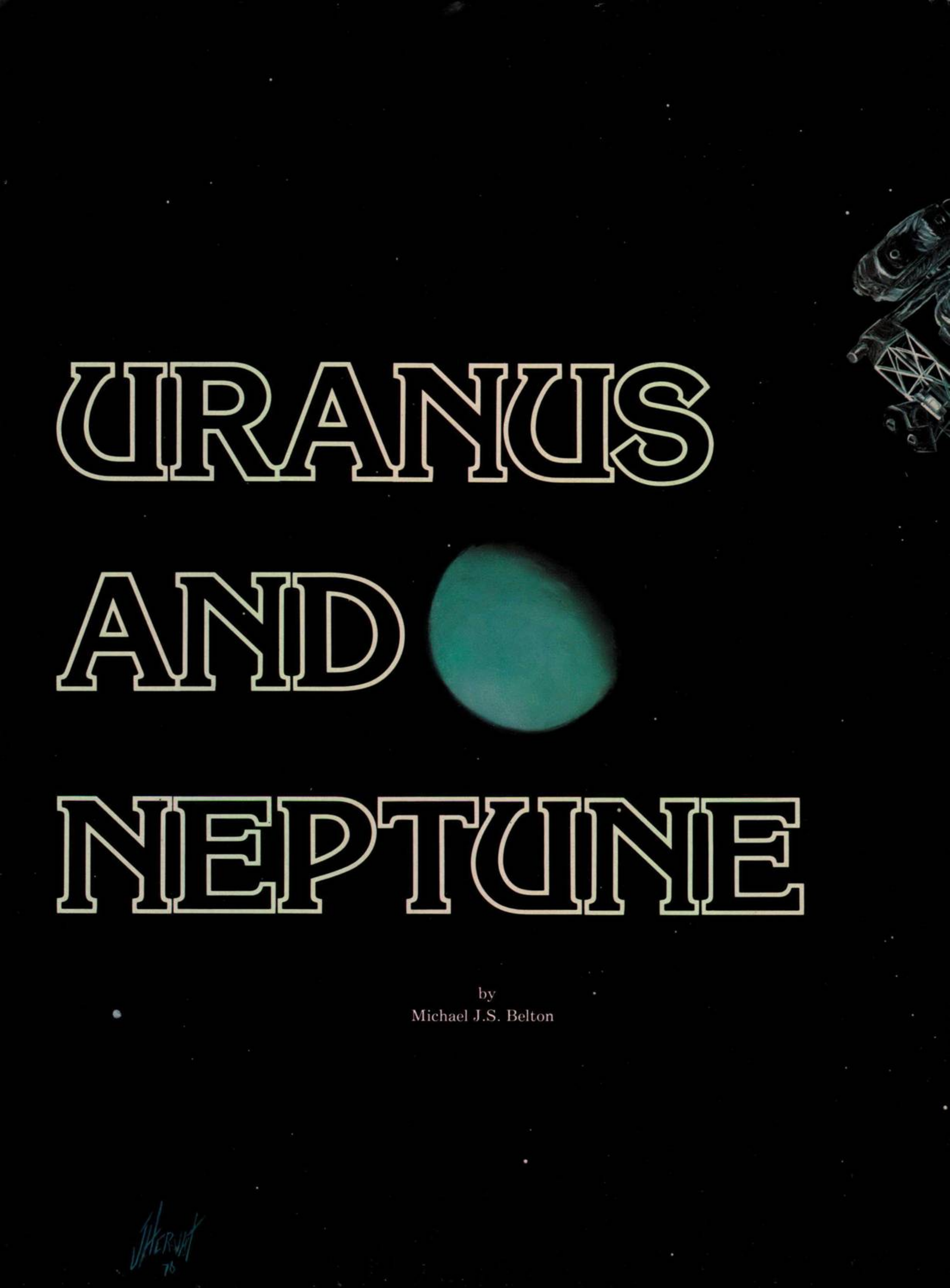
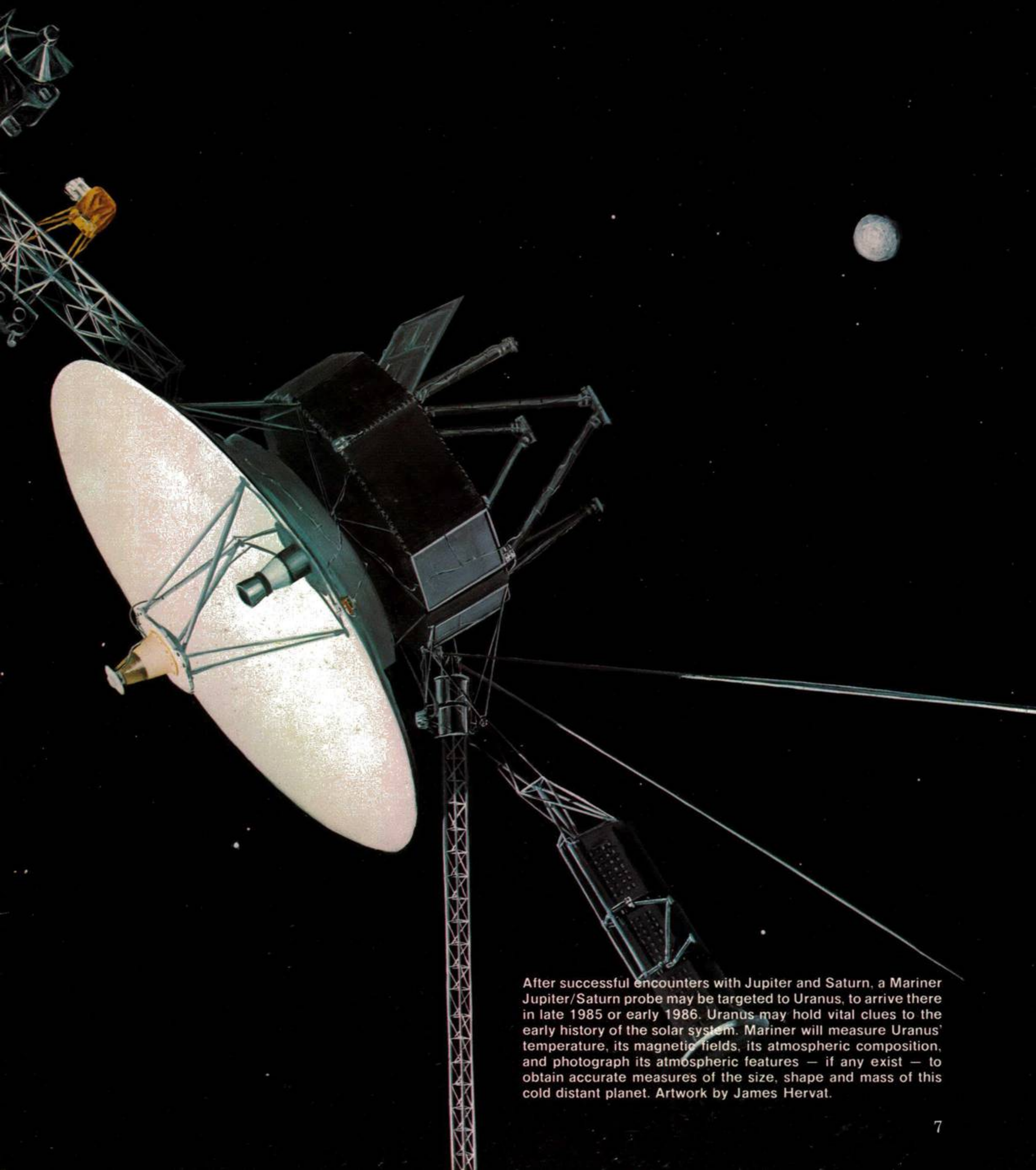
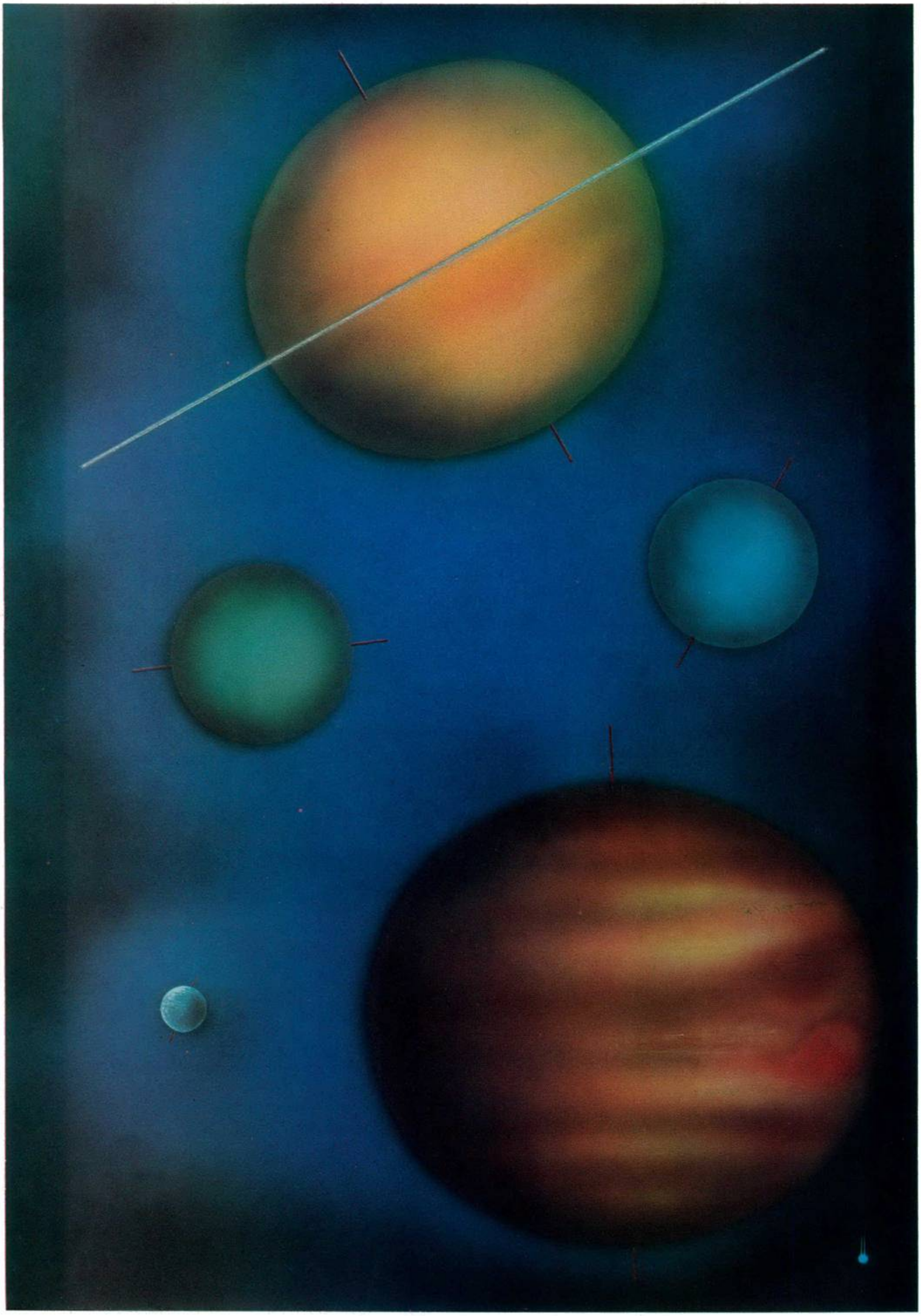


URANUS AND NEPTUNE

by
Michael J.S. Belton



After successful encounters with Jupiter and Saturn, a Mariner Jupiter/Saturn probe may be targeted to Uranus, to arrive there in late 1985 or early 1986. Uranus may hold vital clues to the early history of the solar system. Mariner will measure Uranus' temperature, its magnetic fields, its atmospheric composition, and photograph its atmospheric features — if any exist — to obtain accurate measures of the size, shape and mass of this cold distant planet. Artwork by James Hervat.



Uranus and Neptune lie on the outer fringes of the solar system. Far from the sun that warms Earth (the light that reaches them is weak), they are cold — at least -300 degrees Fahrenheit. Because of their remoteness and faintness, we know less about them than any of the planets nearer the sun. But what we *do* know is fascinating: Uranus and Neptune are planets unlike any others in the solar system.

We cannot ignore Uranus and Neptune. They tell us something very basic about the formation of the solar system, because they are unlike the other giant planets, Jupiter and Saturn, in fundamental ways. The masses of Uranus and Neptune lie midway between the mass of Jupiter and that of Earth, weighing in at roughly 17 Earth masses and 1/17 Jovian mass. Both have higher mean densities than the gas giants; they therefore represent a distinct and special category. Uranus and Neptune are important; any attempt to describe the evolution of the solar system without special reference to Uranus and Neptune would be somewhat akin to an anatomist attempting to describe the functions of the human body without reference to the stomach.

The two planets are closely associated in our minds not only because of their physical similarities and their similar positions in the solar system, but also because the very discovery of Neptune was the result of the analysis of peculiarities in the motion of Uranus across the sky. Neptune was, in fact, the first celestial object whose presence was accurately predicted before discovery. Despite their similarities, however, the two planets are not totally alike. Not only are there important differences in the satellite systems of the two planets, but there may be real differences in their atmospheric and internal structures as well.

Basic Properties

The four most striking facts concerning these intensely cold and immensely distant objects are: *1)* their general similarity in body properties (such as size and shape); *2)* their color; *3)* the uncertainty that exists in our knowledge of their rotation periods, and *4)* the peculiar orientation of the rotation axis of Uranus.

Until recently the uncertainties were even greater, but a rare event occurred in 1968: the occultation of an eighth magnitude star (BD-17° 4388) by Neptune. The occultation allowed Neptune's (and, by inference, Uranus') radius and polar flattening to be precisely determined. A similar event will occur later this year for Uranus: On March 10, 1977, that planet will occult the 8.8 magnitude star SAO-158687. Because of their short duration, and because they are visible only from limited regions of Earth's surface, such occultations are very difficult to observe with precision. Nevertheless, in the last few years they have gained major importance in planetary astronomy. Not only can they yield precise information on size and shape of a planet (which are necessary to understand its internal structure), but — as we'll see later — the detailed shape of the light curve during immersion or emersion from occultation yields direct information on the atmospheric structure.

Why is something so apparently simple as the two planets' rotation periods not known? This can be attributed to their small angular diameter as seen from Earth. Uranus is barely four seconds of arc in diameter at most oppositions, while Neptune is a little more than two seconds of arc across. Such small angular size in the face of atmospheric seeing and strong limb darkening undermines the reliability of the two methods that are generally used to determine the direction and rapidity of rotation: the passage of markings across the face of the disk, and the measurement of the Doppler shift of Fraunhofer lines in sunlight reflected from the planet. The periods given in the table on page 16 were estimated by J.H. Moore and Donald Menzel in the late 1920s from their spectroscopic observations of Doppler shift, using the 36 inch Crosley telescope at Lick Observatory.

Today, however, the accuracy of these observations is undergoing close scrutiny, primarily because of problems in constructing satisfactory mathematical models of the interior structure of Uranus that will simultaneously meet constraints imposed by the rotation period and by observations of the planet's oblateness (polar flattening). Preliminary spectroscopic results obtained in 1976 with the Echelle spectrograph on the 158 inch (4 meter) Mayall telescope at Kitt Peak indicate that Uranus is in fact rotating somewhat more slowly than estimated by Moore and Menzel. John Trauger of the University of Wisconsin physics department recently announced that observations of the Doppler broadening of Fraunhofer lines in sunlight reflected from Uranus indicate a rotation period of 12.3 hours — almost two hours longer than the earlier estimate. A slowly rotating Uranus is more consistent with interior structure models calculated by theoretical astronomers interested in planetology. The situation with respect to Neptune is still unclear.

The spectroscopic technique is susceptible to errors induced by blurring of the image by atmospheric seeing during the time required to register the spectrum. Even with good seeing, the small planetary disks mean that we must make corrections to the observations before we know the true rotation period. It would therefore be of great value to try a different method, such as measuring the

The giant planets — superficially similar but different in composition, mass and density — fall into two classes. Jupiter and Saturn are the supergiants, hundreds of times more massive than Earth, and Uranus and Neptune are giants, tens of times more massive than Earth. An outstanding feature of Uranus, unique among the major planets, is the "side-on" orientation of its polar axis. Earth is included for comparison. Artwork by Mark Paternostro.

The Discovery of Uranus & Neptune

Uranus was discovered by accident in 1781 by English astronomer William Herschel, while he was making a survey for close double stars. His first impression was that he had discovered a new comet, but subsequent observations of its motion and appearance clearly identified it as a massive planet orbiting the sun at a distance of about 19 astronomical units (A.U.). Herschel named it "Georgium Sidus", in deference to King George III, while French astronomers preferred the name "Herschel". "Uranus" was coined by Johann Bode (whose celebrated "law" was later used in the prediction of Neptune), but the name took about 60 years to catch on.

The discovery of Neptune followed after some 65 years of observations of Uranus' motion. Tiny departures from Uranus' calculated position suggested a more distant planet was perturbing its motion. German observers Johann Galle and Heinrich d'Arrest found it on the very same day in which they received a prediction on its position, by mail, from the French mathematician Urbain Leverrier. An independent prediction by John Couch Adams, a noted English astronomer, caused great turmoil over "who gets the credit" — combining the ingredients of international politics, disdain (or, at best apathy) for theoretical predictions, and the continuing struggle between youth and the (in this case, astronomical) establishment. Today, national rivalries have cooled and both men receive due credit for the prediction of Neptune's orbit.

apparent motion of markings across the planetary disk, or identifying short-term periodicities in the planet's brightness. In fact, there is a rich history of this type of research — but with conflicting results. Many great observers of the pre- and early photographic eras reported sighting markings on both planets, as well as variability in brightnes. There are, for example, many reports that Uranus has a belt structure similar to that of Jupiter and Saturn. However, with the exception of special red and infrared observations made with solid state panoramic imaging detectors and hypersensitized, red-sensitive, photographic emulsions, modern observations indicate that the usual appearance of Uranus (and presumably of Neptune) is totally bland. Modern photoelectric photometry has shown no variability due to rotation, and direct high resolution photographs with the 36 inch telescope on the balloon-borne Stratoscope II show no features whatsoever. Only very strong, symmetrical limb darkening is visible. Thus, Uranus appears to have a ubiquitous, structureless cloud cover located deep in the planet's atmosphere.

Why are there so many reports of visual sightings of belts on Uranus, when they are in conflict with the stratoscope pictures? Is it reasonable to assume the visual observers were wrong? In the past, visual observers of planets have proven to be prone to major blunders of overinterpretation; notable examples are Lowell's "canals" on Mars and the misidentification of the 88 day "rotation" period of Mercury. In all cases, however, it seems unquestionable that markings were, in fact, observed. The problem seems to be that the observers overinterpreted what they saw. In the case of "belts" and other reported markings on Uranus, it is likely that faint features do exist, but that they are not necessarily belts.

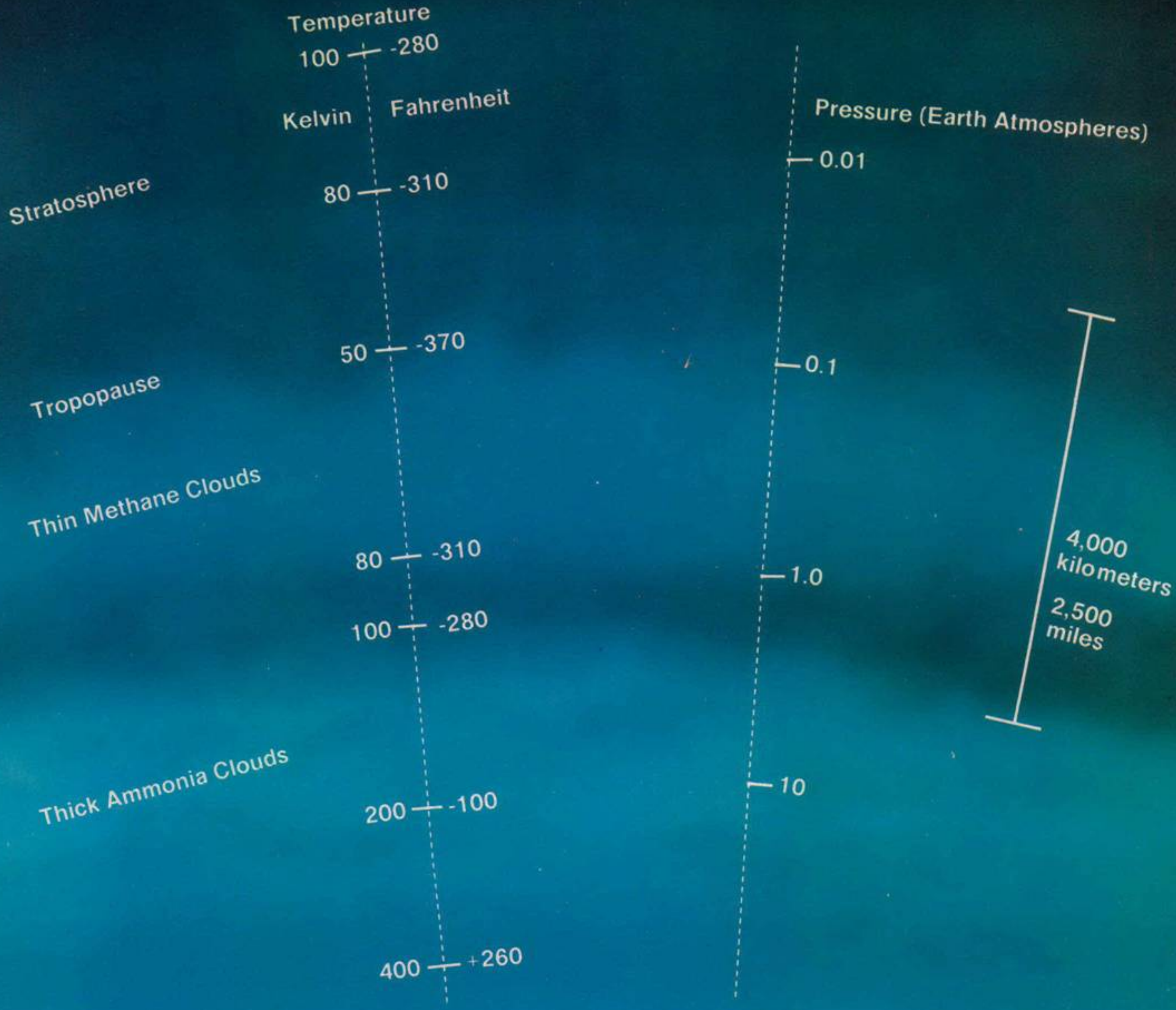
The reported belts are supposed to be inclined by about 25 degrees to Uranus' equatorial plane, as defined by the orbits of its four brightest satellites. In terms of either atmospheric dynamics or celestial mechanics, this does not make sense. We can readily calculate the effects of such a tipped system of atmospheric belts: The observed alignment of the orbits of the satellite system would soon be destroyed by orbital precession. On the other hand, if the planet's true equator is aligned with the plane of the satellite orbits, as is surely the case, then coriolis forces (the same forces that cause the trade winds to blow east-west in Earth's atmosphere) acting in the atmosphere would soon force atmospheric motions to be symmetric about the true equator, and not at some inclination to it. Thus, although markings probably do exist on these planets — with exceptionally weak contrast — they are presently of indeterminate shape.

The general appearance and basic properties of Uranus and Neptune are, therefore, very much alike: They are both about four times the size of Earth, green in color and in rapid motion. Their mean densities are quite low — much less than Earth's 5.5 grams per cubic centimeter — but substantially larger than what would be expected if they had an interior structure similar to that of Jupiter and Saturn. As planets, they clearly represent a type that is quite distinct from either Earth or the two largest planets. They are very cold objects because of their distance from the sun and apparent lack of any substantial internal heat sources. From their extreme positions in the solar system, the sun would appear as a bright — but unresolved — star; Jupiter and Saturn would be much harder to observe than Mercury is from Earth, and Earth, Venus and Mercury might never have been discovered.

Chemical Composition

Uranus and Neptune owe their green color to the chemical composition of their atmospheres. Broad absorption bands, due to the presence of methane (CH_4), are so strong in the spectrum of these planets that one of the bands was discovered as early as 1869 by Father Angelo Secchi, while

The Atmosphere of Uranus



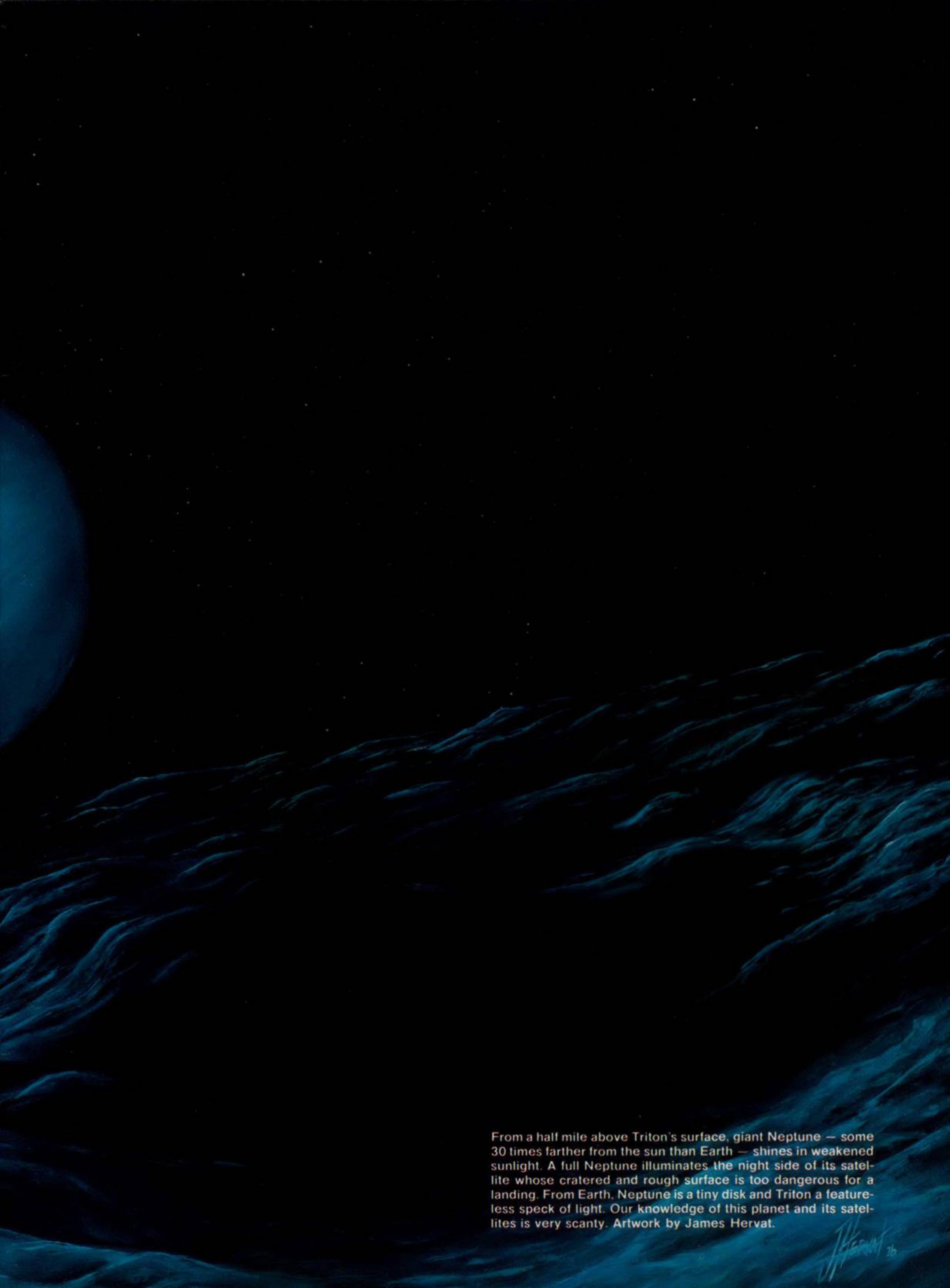
making visual observations of Uranus through a spectroscope! It was not until 1932, however, that Rupert Wildt was able to argue convincingly that these bands on Uranus must be due to absorption by methane gas. These absorption bands are so strong and pervasive at longer wavelengths that they effectively remove all red light from the reflected sunlight, leaving the planet shining with a pale bluish-green color.

To date, only two molecules have been identified with certainty on these planets: methane and molecular hydrogen. The discovery of molecular hydrogen was made by Gerard Kuiper and Gerhard Herzberg, as a result of Kuiper's 1949 observation of a diffuse absorption band near 8270 Angstroms in the spectrum of Uranus. Since that time, other absorptions of molecular hydrogen have been found in both planets. Their very appearance means that enormous amounts of hydrogen must exist in the visible atmosphere.

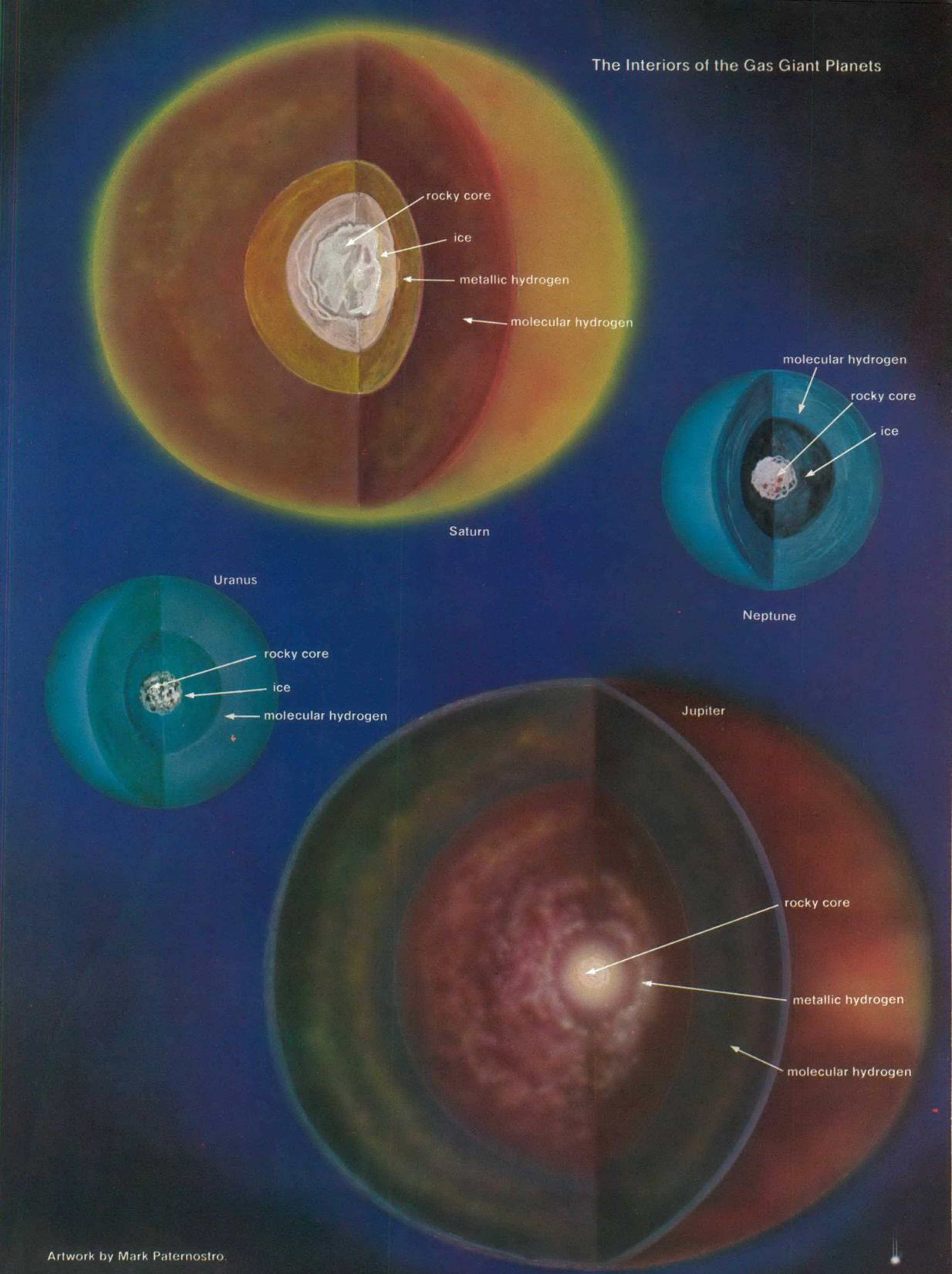
Other molecules surely exist on Uranus and Neptune; their presence, however, may be obscured by the massive absorptions (blanketing) by methane. Or, they may simply be unrecorded, because some molecules do not produce spectral absorptions in the visible spectrum. Also, since these planets are cold, it may be that some gases have "snowed out" and exist only at deeper, largely unprobed, levels of the atmosphere. This last category most certainly includes ammonia (NH_3) and water (H_2O), which theoretically should be present in large quantities on both planets. At the coldest temperatures that are thought to exist in Neptune's atmosphere, methane and argon also may have snowed out.

Among the gases that have no absorptions in the observable part of the spectrum, we expect large quantities of helium and neon. Both are cosmically abundant, and would be gravitationally trapped on these planets.

Molecular hydrogen is, by far, the major constituent of Uranus' atmosphere. According to Andrew McKeller, a theoretical physicist, there are 40 to 70 times more hydrogen molecules covering each square foot of Uranus than there are from all the gases in Earth's atmosphere, on each square foot of Earth. Also, Uranus is much larger than Earth, meaning Uranus' hydrogen atmosphere (even though hydrogen is very light, compared to air) con-



From a half mile above Triton's surface, giant Neptune — some 30 times farther from the sun than Earth — shines in weakened sunlight. A full Neptune illuminates the night side of its satellite whose cratered and rough surface is too dangerous for a landing. From Earth, Neptune is a tiny disk and Triton a featureless speck of light. Our knowledge of this planet and its satellites is very scanty. Artwork by James Hervat.



The Interiors of the Gas Giant Planets

rocky core
ice
metallic hydrogen
molecular hydrogen
Saturn
molecular hydrogen
rocky core
ice
Neptune
Uranus
rocky core
ice
molecular hydrogen
Jupiter
rocky core
metallic hydrogen
molecular hydrogen

Artwork by Mark Paternostro.

tains about 50 times more mass than Earth's! Methane is rare by comparison: somewhere between 1 in 100 to 1 in 1,000 molecules is a methane molecule; the others are hydrogen. So Uranus' atmosphere — if transported to Earth — could provide a limitless source of high grade fuel!

While it is a complex and technical subject, the chemical composition of the atmospheres of Uranus and Neptune is extremely important, because of the limits it places on speculations about the origin of these planets and their internal structures. For example, if methane were found in the same proportion to hydrogen on all the outer planets (Jupiter and Saturn are already known to have roughly the same methane/hydrogen mixing ratio), then it would make sense that methane was most probably included in all the outer planets by the same processes that led to the accumulation of hydrogen, helium and other gases that don't freeze. This would presumably render unlikely the chief alternative — that methane was accumulated in protoplanetary bodies by virtue of being trapped in a weakly bound clathrate form in the water or ammonia ice. At present, the only number we know for Uranus and Neptune is the methane/hydrogen mixing ratio — and this with great uncertainty.

Structure

The internal structure of Uranus and Neptune has most recently been investigated by Maurice Podolak of Tel Aviv University and A.G.W. Cameron. Early work had shown that planetary models that contain large amounts of hydrogen, closely reflecting the solar composition, could not explain the observational limits imposed by the mean density and radius of Uranus. They simply couldn't "build" a heavy enough planet with hydrogen. These planets, then, must be largely composed of water ice and ammonia ice, surrounded by only a modest atmospheric veneer of hydrogen, helium and methane. The outer planets would have been first accumulated as rapidly growing conglomerates of rocky and icy materials. After reaching a critical size, they were able to trigger the gravitational collapse onto their surfaces of gases from the solar nebula in their general vicinity. In the case of Jupiter and Saturn, a great deal of nebular gases were attracted, while for Uranus and Neptune the rocky, icy conglomerate nucleus remains the primary component. It is this distinction which underlies the importance of Uranus and Neptune to cosmogony: *In Jupiter and Saturn we observe primarily the results of dynamical collapse of material from the solar nebula, while in Uranus and Neptune we observe principally the results of the initial accumulation process.*

Despite this understanding, the mathematical models that have been constructed to explain the interior structure of Uranus and Neptune have not, in fact, been very successful. While it is possible to define an interior structure to meet the relatively well-defined observations of the mean density and radius, none of the models can reproduce the observed flattening of the planets. For example, if Uranus' rotation period were really as short as 10.8 hours, than the observed flattening of the planet should be *twice* what it is. For Neptune, the situation is not quite so bad, though a major discrepancy still exists. Both of these problems would be largely solved if Uranus' rotation period was longer, and Neptune's was shorter, than the currently accepted estimates of Moore and Menzel. As we've already discussed, this is probably the case for Uranus; thus, the problem should soon be solved.

The internal structures of Uranus and Neptune should be very similar to one another. The *core* is probably composed of about 1-1/2 Earth masses of rocky material at a temperature of 3,000 to 5,000 degrees Fahrenheit (2,000 to 3,000 degrees Kelvin). Some of this material, primarily iron compounds, may be in metallic form, and may provide the basis for a magnetic field. Recently Larry W. Brown of Goddard Space Flight Center has found radio bursts emanating from Uranus, in IMP-6 spacecraft data. Radio bursts require the existence of a well-developed magnetosphere, such as Jupiter has, around the planet. Since a substantial magnetic field is needed to produce the magnetosphere, the radio bursts tend to support the rocky-metallic core hypothesis.

Most of these planets' interiors should be a thick *ice mantle* — mainly water, with a mixture of ammonia surrounding the core. The mantle would extend to about 2/3 of the apparent radius of the planet, and make up some 50 percent of the total mass. If a distinct surface exists in these planets, it would be at the boundary of this ice mantle at a pressure several hundred thousand times that at Earth's surface, at a temperature of a few thousand degrees. The remainder of the planet would consist of a very deep atmosphere, composed mainly of hydrogen and helium. Although extensive, the atmosphere would only account for approximately 20 percent of the total mass. In contrast, Jupiter and Saturn, the gas giants, have a predominantly hydrogen envelope making up 80 to 90 percent of the total mass. With the terrestrial planets, only rocky cores exist, and the atmospheres amount to an infinitesimal fraction of the planets' masses.

Uranus and Neptune clearly have very deep, extensive atmospheres when compared to the atmospheres on Earth, Venus and Mars. Direct observational evidence on their detailed structure is available through spectroscopic, photometric and radiometric observations; however, only the topmost layers are probed. Both planets are thought to have the same basic atmospheric structure: a relatively hot stratosphere, and a very cold tropopause (about -400 degrees Fahrenheit or 50 degrees Kelvin) near the 100 millibar pressure level. Lower parts of the atmosphere find temperatures increasing with depth. Unlike Jupiter, which has clouds near the

Basic Properties of Uranus and Neptune

Property	Uranus	Neptune
PHYSICAL		
Mass	8.73 x 10^{28} gm (14.6 Earth)	1.03 x 10^{29} (17.2 Earth)
Radius	*25,600km (3.98 Earth, or 15,900 miles)	24,500km (3.88 Earth, or 14,500 miles)
Mean Density	*1.2gm/cm^{-3}	1.6gm/cm^{-3}
Rotation Period	*11 hours	*16 hours
Inclination of Polar Axis	97° 53'	28° 48'
Oblateness		
Dynamic	*0.05	*0.02
Optical	*0.02	0.026
Effective Temperature	62° K (-350° F)	46° K (-377° F) (internal heat source?)
ORBITAL		
Semimajor Axis	19.18 A.U.	30.06 A.U.
Inclination to Ecliptic	46'	1° 47'
Orbital Velocity	6.8km/sec^{-1} (4.3 mi/sec)	5.4km/sec^{-1} (3.8 mi/sec)
Eccentricity	0.0472	0.0086

*denotes that considerable uncertainty exists

top of its atmosphere, thick clouds are anticipated only in the deeper parts of the atmosphere. They may be barely visible at normal optical wavelengths. However, Uranus may have a high layer of methane cirruslike clouds near the tropopause. Neptune is colder; its high level clouds (if any exist) would be made of frozen argon crystals.

In Neptune's stratosphere, temperatures are expected to have maximum values near -210 degrees Fahrenheit (140 degrees Kelvin). This temperature is very high for an outer planet; it exists because methane has strong absorption bands in the infrared. Thus, large amounts of solar energy are absorbed directly in the upper atmosphere. Results from the occultation of BD-17° 4388 gave indirect observational evidence for temperatures of 135 to 200 degrees Kelvin in the high atmosphere; furthermore, there are unpublished reports that Neptune has an infrared methane emission band (at 7.8 microns wavelength) that confirms it has a hot stratosphere. This infrared band has not been observed on Uranus, leading astronomers to suspect there may be some fundamental difference between Neptune and Uranus.

Laurence Trafton, a planetary spectroscopist at the University of Texas, has argued that there are very definite indications that Neptune may have, unlike Uranus, a substantial source of *internal energy*. There are indications (admittedly difficult to substantiate) from photometry in the far infrared part of the spectrum that Neptune radiates more energy than it receives from the sun. According to Trafton, this highly debatable proposition is supported by the methane absorption lines observed on Neptune, which are just as strong as those on Uranus. This would not be true unless Neptune's visible atmosphere were at least as warm as Uranus'! But Neptune's atmosphere should be colder than that of Uranus; in fact, most of its methane should be "snowed out" into a thick cloud. If the infrared methane emission is indeed present on Neptune and not on Uranus, Trafton's viewpoint would be greatly strengthened. An important observation that may decide this important point will be the upcoming occultation of SAO-158687: If analysis of the light curve shows Uranus to have a very cold stratosphere, then Trafton's suggestion — that Neptune generates its own internal heat — will have to be taken very seriously. Of course, there are always other possible explanations.

Below the tropopause, the atmospheres of both planets are expected to have at least two cloud layers — a methane cloud high in the atmosphere, and a thick ammonia cloud with its base deep in the atmosphere. Observational evidence based on the limb darkening seen in the Stratoscope II pictures indicates deep, thick ammonia clouds on Uranus. The situation with respect to the upper methane cloud is ambiguous, as spectroscopic studies show no trace of them. Such clouds must be either very broken up, or just very thin.

The weather on Uranus and Neptune must be calm. The motion of their atmospheres is expected to be quite weak and streamlined because the driving energy from the sun is so small (19 to 30 astronomical units from the sun). Winds may be on the order of two miles per hour (one meter per second) — a very placid situation. Even with the peculiar upside-down orientation of its rotation axis — which means that averaged over a Uranian year, the polar regions receive more energy than the equatorial region — Uranus is not expected to produce peculiar seasonal or climatic effects because of the very long time it takes to warm up its hydrogen atmosphere. The Uranus atmosphere would take some 600 to 700 years — or about 8 Uranian years — to respond to a change in heating. From daily experience, we know Earth's atmosphere responds far more rapidly.

Satellites

There are five satellites known to orbit about Uranus, and two around Neptune. These two satellite systems are amazingly different — so much so that a number of researchers have suggested that a dynamical "catastrophe" must have taken place in the vicinity of Neptune.

Ariel, Umbriel, Titania and Oberon, the four brightest (about 14th magnitude) satellites of Uranus, form a physically homogeneous set in very regular orbits about their planet. Only Miranda, the faintest and closest of the Uranian satellite family, may have a distinctive, modestly inclined, and slightly eccentric orbit not in keeping with the characteristic harmony of the system.

In contrast, Neptune's satellite system is startling. At 13.6 magnitude, Triton — which may be the largest satellite in our solar system — moves in a rapidly decaying retrograde orbit. From the dissipation of energy in the tides that Triton must raise on Neptune, astronomer Thomas McCord of the Massachusetts Institute of Technology has calculated that Triton must undergo changes in its orbit which could be measurable within a few decades.

Neptune's other moon, Nereid, is a miniscule body (19.5 magnitude) in comparison to Triton. It, too, has a peculiar orbit, moving prograde (nonretrograde), but with the most highly eccentric satellite orbit in our solar system (its eccentricity is 0.76). Something very special must have happened in the Neptunian system, most probably within the last billion years. The most prominent suggestion on the nature of this event was proposed by British mathematician Raymond Lyttleton in 1936: If Neptune had had two large satellites (about the size of Triton) in rather eccentric and direct orbits, then it was mechanically *possible* that an encounter between them could have resulted in one of them assuming the present orbit of Triton, while the other escaped from the Neptunian system. Lyttleton identified the escaped satellite as Pluto. His proposal is attractive because of three circumstances (he was originally aware of only one): *1)* the orbital path of Pluto is peculiar among planets, in that it brings Pluto nearer the sun than Neptune; *2)* the photometric colors of Pluto are similar to those of the satellites of Saturn, Uranus and Neptune, and are quite distinct from the colors of the planets, and *3)* as Gerard Kuiper has noted (in the context of an alternative scheme for Pluto's escape from the gravitational hold of Neptune), Pluto rotates with a period of 6.4 days — which is to be expected from synchronous rotation if Pluto had originally been in orbit about Neptune near the current orbital distance of Triton. Together, these factors seem to make a persuasive case for the idea that a catastrophic collision did occur between the two major satellites in the Neptune system; the current disarray of the orbits of Triton, Nereid and Pluto may be the result.

In astronomy, the discussion of one catastrophe often leads to the realization of the possibility of yet another. This is also the case here. For example, Richard Greenberg of the Planetary Science Institute in Tucson, Ariz., has described a scenario for the evolution of the Uranian system to its present, highly organized state, which also involves a catastrophic situation. The original Uranian system would have been composed of the planet and a rather large satellite in a retrograde orbit. As is presently the case with Triton, tidal dissipation leads to a rapid decay of the orbit, and the satellite spirals in toward Uranus. If the original satellite were massive enough, it is possible that the process would result in tilting the polar axis of Uranus to the peculiar orientation that we see today. In any event, the hypothetical satellite would continue to approach until either a direct collision occurred, or more likely, it broke up under tidal stresses into much smaller fragments.

Of course, all these processes are highly speculative, chiefly because of an almost total lack of physical data. For instance, Triton may or may not be the largest satellite in the solar system; the satellites of Uranus may or may not be very similar to one another and to the satellites in other systems, and Pluto may or may not be an escaped satellite of Neptune. Whatever the facts are, we can be assured that we are on the brink of major discoveries with regard to these systems. When NASA orbits the Space Telescope, our knowledge of the outer planets will "explode". Good photometric and spectroscopic measurements will rapidly sort out truth and speculation.

Also, if all goes well, we can expect the Uranian system — and perhaps even the Neptune system — to be visited within the next 15 years by one of the Mariner Jupiter/Saturn spacecraft which will be launched this year. The craft will follow a trajectory which, after encounter with Saturn, will take it to Uranus by January 1986. Neptune, although admittedly an unlikely possibility for this particular spacecraft, could be reached five or six years later. The possibilities for a mission to Uranus look good, and plans are actively being made. We can therefore expect some of the speculations discussed here to be ultimately resolved.

Dr. Michael Belton is an astronomer at Kitt Peak National Observatory, with interests in planetary atmospheres and high resolution spectroscopy. He is also involved in space probe work as a member of the Mariner 10 Television Team (studying the motions of Venus' atmosphere). He was involved in planning the now-canceled Mariner Jupiter/Uranus mission, and is currently a member of the Science Working Group for a "solar sail" mission to Halley's Comet.

PLUTO

by
Ray L. Newburn Jr.

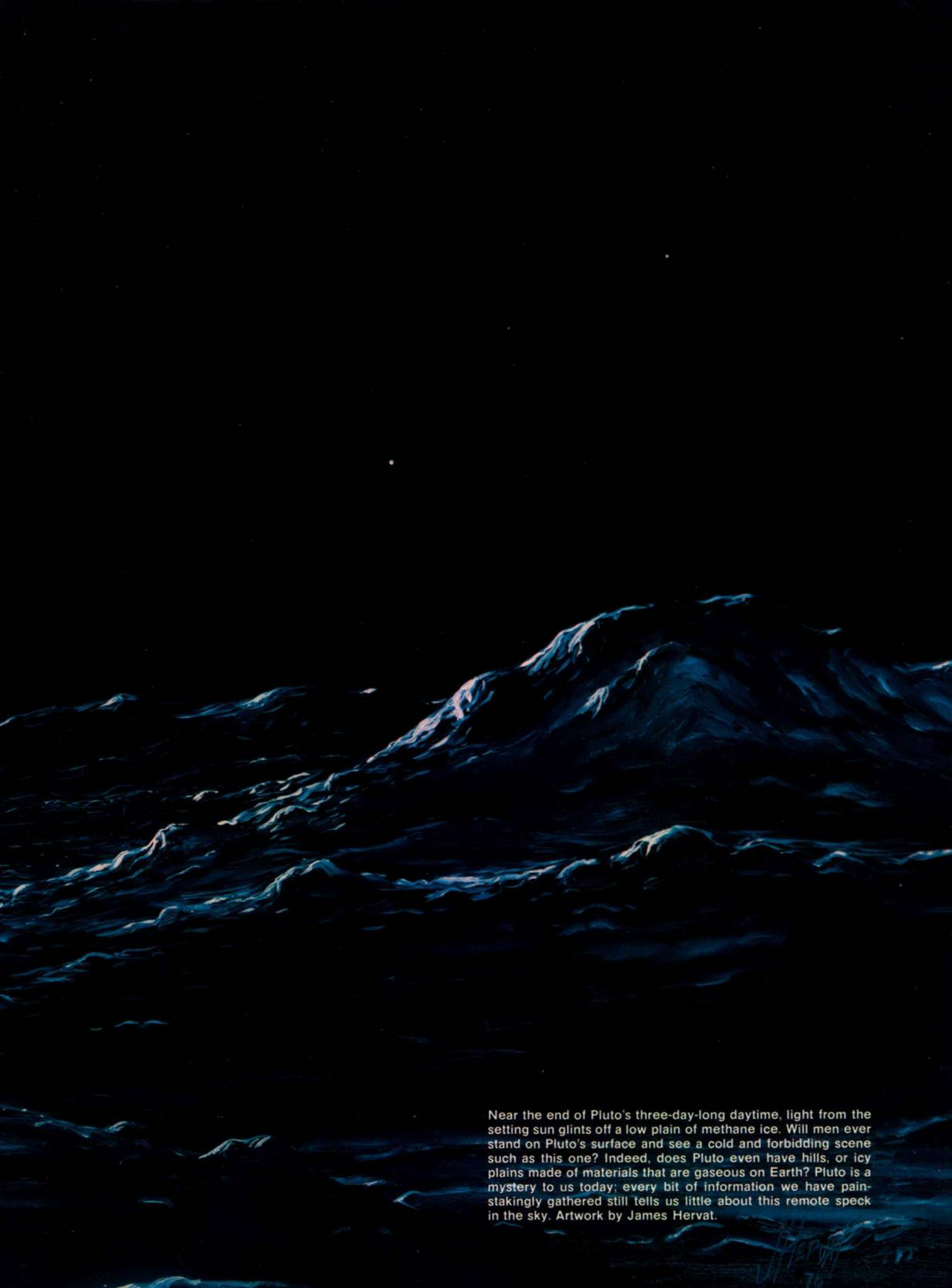
In any list of the members of the solar system, the name "Pluto" will conjure up all kinds of romantic notions, usually associated with its status as the most distant of all the planets from the sun. But when you consult your books, you'll find that there usually isn't very much said about Pluto. Pluto rates a paragraph or two at the end of a chapter on the outer planets, and statistical tables often present a row of question marks or blank spaces after Pluto's name. Almost 50 years after its discovery, we still know virtually nothing for certain about Pluto.

The third planet to be discovered in historical times, Pluto could not have been found in the same way that Uranus and Neptune were. Uranus was discovered entirely by chance, by Sir William Herschel in 1781. Perturbations in its predicted orbit led to independent calculations — by John Couch Adams in England and Urbain Leverrier in France — that possibly an eighth planet was causing the distortions. In 1846, Neptune was found near where both men had predicted it would be. Pluto required an intense search with a powerful astrographic camera before it was found.

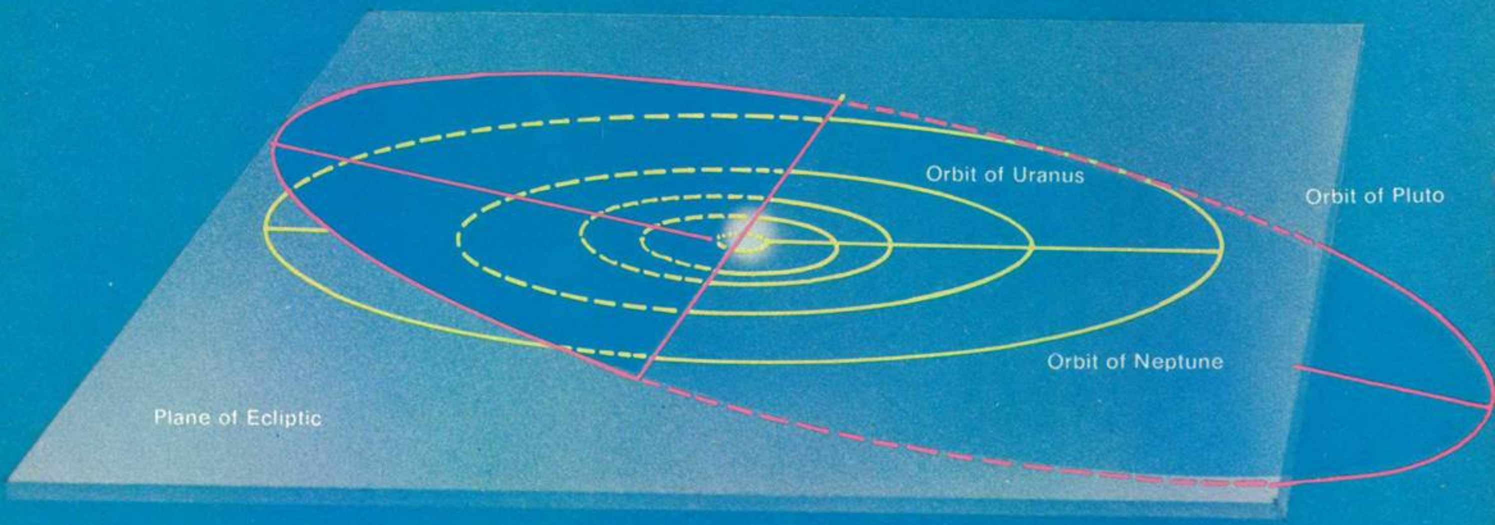
Remote Pluto, just a speck of light in Earth based telescopes, is distinctive because it moves against the stellar background. Even though a telescope of 10 or 12 inches aperture is needed to see Pluto, a much smaller telescope can photograph it — chiefly because an observer can sort its image apart from the myriad background images by comparing pictures taken on different nights. Such a technique was used originally to find the planet in 1930. Lick Observatory photograph.

Within a week of Neptune's discovery, Leverrier was speculating that there might be even more planets beyond Neptune. As it turned out, the deviations in the orbital motions of Uranus could not be fully explained even by the discovery of Neptune. Soon, experts in celestial mechanics were again attempting to guide the search for a new planet. Most scientists, when trying to solve for its location, assumed the existence of a single body the size of Uranus or Neptune at a distance of 40 or 50 astronomical units (3-1/2 to 4-1/2 billion miles) from the sun — although others discussed the possibility of two or even three planets at varying distances. The most detailed and promising predictions were those of William H. Pickering and Percival Lowell, published in 1909 and 1915 respectively. Although they did not agree, and neither was a really successful prediction, searches for a new planet were carried out at the Lowell Observatory in Flagstaff, Ariz., during 1905-07 and again in 1914-16. The latter was based specifically upon Lowell's predictions, but both were unsuccessful. A search made in 1919 at Mount Wilson Observatory, based upon Pickering's work, also found nothing.

The technique used in both these planet searches was fairly simple in conception. Identical photographic plates of a given area of the sky were exposed a few days apart, after which they were compared



Near the end of Pluto's three-day-long daytime, light from the setting sun glints off a low plain of methane ice. Will men ever stand on Pluto's surface and see a cold and forbidding scene such as this one? Indeed, does Pluto even have hills, or icy plains made of materials that are gaseous on Earth? Pluto is a mystery to us today; every bit of information we have painstakingly gathered still tells us little about this remote speck in the sky. Artwork by James Hervat.



Pluto's orbit (shown in red) is quite different than those of the other outer planets (shown in yellow). Pluto's orbit is inclined some 17 degrees to the plane of the ecliptic, and is markedly eccentric. At perihelion, Pluto is closer to the sun than is Neptune, while at aphelion it is half again as far from the sun as Neptune is. Diagram by Bruce Precourt.

in a device called a *blink microscope.* Although there are various ways to design such an instrument, the basic method is to identically align and illuminate the two plates, side by side, inspecting each in turn by flipping a mirror back and forth in the optical train. The flipping was usually done by hand during the early searches; in modern systems, an electric drive moves the mirror. Image persistence in the eye causes a stationary object (such as a star) to maintain an apparent steadiness in the eyepiece, while a moving object (such as a planet or asteroid) jumps back and forth.

The blink microscope method of search isn't as easy as it sounds. In addition to possible new planets, asteroids and plate flaws also jump, variable stars wink, and about 50,000 stars per plate just sit there — but still add to the confusion.

A third search for "Planet X" — as Lowell had called the possible new body — was instituted at Lowell Observatory with new equipment in 1929, more than 12 years after Lowell's death. It was there that Clyde W. Tombaugh found Pluto on Feb. 18, 1930, while blinking a pair of plates he had obtained on Jan. 23 and 29. After Tombaugh and others followed the object for several weeks to be sure of its true nature, the discovery of the long sought planet was announced on March 13, 1930 — Lowell's birthday. The name "Pluto", the mythological brother of Jupiter and Neptune, seemed suitable, especially because the first two letters were Percival Lowell's initials.

Today, it seems unlikely that Pluto is the actual object predicted by Lowell, since he had assumed a body with seven times Earth's mass; Pluto's mass is more like 1/10 that of Earth. Although one of Lowell's two solutions lay in the right part of the sky, Pluto could not have caused the observed deviations in the motion of Uranus, simply because its mass is too small. (In fact, there remains a problem with the motion of Uranus to this day, small but unexplained.) No one can deny, however, that the search initiated by Lowell and carried on by his followers resulted in Pluto's discovery.

Most of the time, Pluto is the most remote object in the solar system, except for long period comets. We must say "most of the time" because Pluto travels a most unexpected path around the sun. The orbits of the other planets are nearly circular, while that of Pluto has proved to be highly eccentric or elongated. At perihelion (the point of an orbit closest to the sun), Pluto comes nearer to the sun (2.75 billion miles or 4.42 billion kilometers) than Neptune can ever come (2.77 billion miles or 4.46 billion kilometers). At aphelion (the orbital point farthest from the sun), Pluto is an enormous 4.59 billion miles (7.38 billion kilometers) distant. At aphelion, Pluto is almost 50 times farther from the sun than Earth, receiving only 1/2,500 as much solar energy on a given area of its surface.

Not only is the orbit of Pluto elongated; it is also highly inclined, tilted by more than 17 degrees to the ecliptic (the plane of Earth's orbit around the sun). No other outer planet departs from that plane by more than 2-1/2 degrees. Pluto at aphelion, therefore, lies 1.24 billion miles (2 billion kilometers) below the ecliptic plane. This departure is fortunate: The orbits of Pluto and Neptune never actually cross because they lie in different planes.

Pluto and Neptune are in a *resonance.* Three times Neptune's period of revolution about the sun is very nearly equal to twice Pluto's period. In other words, Neptune goes around the sun three times in the time it takes Pluto to go around twice; at the end of every sun period, the two planets are in the same places (relative to each other) in their orbits. Studies of the long term stability of this and other resonances in the Neptune-Pluto system have shown that for millions of years, the two planets can not have approached each other closer than 1.5 billion miles (2.5 billion kilometers). Therefore, very little danger of collision exists. In fact, on occasion Pluto comes much nearer to Uranus — about 1 billion miles (1.6 billion kilometers).

This resonant stability becomes even more interesting because of speculations that Pluto might be an escaped satellite of Neptune. (Pluto is physically much more like Neptune's larger satellite, Triton, than one of the giant planets.) The Neptune-Pluto resonance, which holds them so far apart, guarantees that any such escape must have occurred very far in the past, when other resonances of much longer period may have overcome the dominant ones we know about.

Just what sort of planet *is* remote Pluto? That question is more difficult to answer than for any other planet, largely because Pluto is so small and distant. On photographs, Pluto looks exactly like the background stars. In 1950, Gerard P. Kuiper made a direct measurement of Pluto's diameter, using a "disk meter" on the 200 inch telescope at Mount Palomar. The disk meter produces an articificial "star" of adjustable brightness, color and diameter, to be visually matched with the measured object. During a period of excellent seeing, Kuiper obtained an angular diameter of 0.23 seconds of arc, which is equivalent to about 3,660 miles (5,900km). Realistically, however, the uncertainty must be rather large — at least 1,000 kilometers either way. An upper limit on Pluto's diameter of 4,225 miles (6,800km) was set a decade ago when the planet did not occult a star that lay very close to its path.

Pluto's mass is even less certain than its diameter. The mass of a planet can be easily determined if the planet has a satellite, but no satellites circling Pluto have been discovered. About all we can do is something similar to the Neptune discovery method: Given the orbit and present location of Pluto, what must its mass be in order to bring about observed effects in the motions of other nearby planets? Unfortunately, even this technique won't work too well because Pluto is small, no other planets are very near, and Pluto's orbit is not really well known. It has been followed for only 47 years — less than 1/5 of one revolution around the sun since its discovery.

The best mass figure currently available for Pluto puts its mass at 11 percent that of Earth. This may prove to be totally incorrect, since very small parameter changes for other bodies in the solar system may account for part or all of the effect presently attributed to Pluto. But the actual mass seems unlikely to be very much greater than 11 percent that of Earth; that mass, and Kuiper's diameter, together imply a Plutonian mean density higher than Earth's density of 5-1/2 grams per cubic centimeter (5-1/2 times that of water). All known densities for the planets and satellites in the outer solar system are much lower than this figure, and the density of Pluto should be (and probably is) lower too.

Thus, we know very little about the most basic properties of Pluto; its diameter, mass and density are all uncertain. But Pluto's period of rotation can be determined with considerable accuracy, even though it can be seen only as a point of light. If some regions on a planetary body reflect more sunlight than others, then the planet will appear brighter when those regions face the sun. By phasing photoelectric light curves (matching up accurate, repeated measurements of brightness), scientists can determine the exact time necessary for a given feature on Pluto to reappear as seen from Earth. The longer the planet is watched, the smaller any error becomes. Pluto has been watched for 20 years, and its day is now known to be 6.38737 days in length, with an uncertainty of only about 15.5 seconds.

Although the period of Pluto's brightness variations has remained constant over 20 years, their amplitude, or size, has not: It has doubled. At the same time, Pluto's average brightness has decreased 20 percent. Astronomers Leif Andersson and John Fix have suggested that the different angle from which we now view Pluto as it has revolved around the sun enhances the reflectivity variations, while decreasing the reflectivity itself. For such changes to occur, Pluto's axis must be tipped at an angle probably greater than 50 degrees from the perpendicular to the plane of its orbit. (By comparison, Earth's axis is tipped 23-1/2 degrees.)

Since the size of Pluto is not known with much accuracy, neither is its reflectivity. Since reflectivity can yield vital clues to a planet's composition, astronomers have tried to determine how

How Small Is Pluto?

Estimates of Pluto's diameter have shrunk considerably since Lowell and Pickering first hypothesized a possible "Planet X". The actual planet, found in 1930, turned out to be much smaller than the Uranus sized body suggested by Lowell; as Newburn states in his article, Gerard Kuiper obtained a diameter in 1950 of about 3,660 miles. Additional estimates of Pluto's diameter have often been even lower.

Recent measurements made from the spectroscopic observations of Dale Cruikshank, Carl Pilcher and David Morrison at Kitt Peak National Observatory indicate that Pluto may, in fact, be slightly smaller than Earth's moon. Since the spectroscope reveals that Pluto is covered with methane ice, it is more highly reflective than it would be if its surface were composed solely of dark rock. When scientists compare Pluto's reflectivity with that of other ice covered bodies in the solar system whose diameters we know with certainty, Pluto's maximum diameter turns out to be only 2,100 miles (3,300km) — and it may be as small as 1,700 miles (2,800km). In comparison, the diameter of our moon is about 2,160 miles (3,476km).

If Pluto is this small, its mass must be much lower than that currently estimated (about 1/10 that of Earth). Such a small mass could not possibly have produced the perturbations in the orbits of Uranus and Neptune that supposedly indicated the ninth planet's position. Pluto's discovery thus becomes truly "accidental", and leaves us with a perplexing — and intriguing — question: Could there be an actual, unfound planet that *did* cause those perturbations?

bright, and what color, Pluto is. But the light from Pluto that enters an astronomer's telescope could be reflected from a large, poorly reflecting planet or a small, highly reflecting one. Changes in reflectivity, however, can be measured (since we can reasonably assume the planet's size doesn't change), and the *relative* reflectivity also can be measured as a function of wavelength, or color, of light. For example, Pluto is more reflective in red light than in blue light; as seen visually, Pluto would be yellowish in color. Its reflectivity shows a very gradual increase from the violet to the near infrared end of the spectrum — similar to some stony-iron or low-nickel iron meteorites.

Reflectivity can be measured at wavelengths invisible to the eye. Scientists Dale Cruikshank, Carl Pilcher and David Morrison recently made an interesting new observation with the 158 inch (4 meter) reflector at Kitt Peak National Observatory. Laboratory experiments had shown that water or ammonia frosts show a low ratio of reflectivity when comparing infrared light of wavelength 1.55 micrometers to 1.73 micrometers, while methane frost shows a high ratio. Their observations of Pluto, while definitely rejecting water or ammonia frosts, were consistent with the presence of methane frosts. This doesn't prove that methane frost is actually present, but there is no other likely explanation of the observations. If Pluto is indeed covered, at least partially, with methane frosts, then its reflectivity should be *higher* than obtained using Kuiper's diameter. Therefore, Pluto may be considerably smaller than 3,660 miles.

Another fact that suggests the presence of methane frost on Pluto is its extreme cold. Pluto is so far from the sun that even if its surface is quite dark and absorptive (as implied by the Kuiper diameter), the average dayside temperature would be just under about -370 degrees Fahrenheit (50 degrees Kelvin). The presence of frozen methane is quite possible at such a temperature, and it's not surprising that no atmosphere has been detected: It would have frozen on the surface.

Our knowledge of Pluto is the most limited of any planet. We can eventually expect to obtain a better value of its mass as we follow it around a larger fraction of its orbit, and a better diameter value as occultations of stars occur — as they must, sooner or later. Improved mass and diameter values will help us obtain improved values for density, reflectivity and temperature — those basic numbers that tell us what a planet is apt to be like. After these gradual improvements, further knowledge must await the space probes of the future.

Are there planets beyond Pluto? After the discovery of Pluto, the Lowell Observatory staff continued (until 1943) to search the sky for additional planets, covering most of the sky within 30 degrees of the ecliptic to magnitude 16-17, and most of the sky within 40 degrees to magnitude 14-15. Nothing was found. When we consider that the visual magnitude of Pluto at its *average* distance from the sun is 14.9, and even as it nears perihelion it is only about magnitude 14.0, we must conclude that *if* there are planets beyond Pluto, they are small or considerably farther from the sun — or both. There's no proof that other planets don't exist, and eventually they may be found. Meanwhile, tiny Pluto travels its lonely, eccentric path in the bitter cold of space — the solar system's dark frontier.

Ray L. Newburn Jr. has worked at the Jet Propulsion Laboratory in Pasadena, Calif., for over 20 years. In the last decade, he has worked on advance mission planning and has done research on the outer planets, asteroids and comets. Currently he is helping to plan a space probe rendezvous with Halley's Comet at the time of its perihelion in 1986.

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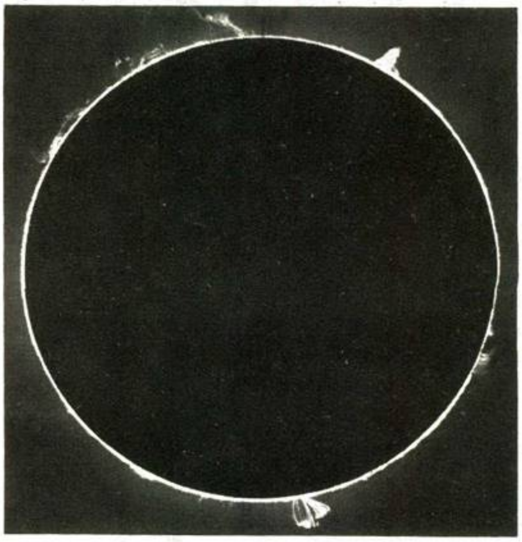

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STELLAR FRONTIERS

Miniblack Holes

by
Barry Parker

Throughout most of its life, a star is a delicately balanced sphere of gas. Its inward pull of gravity is held back by an equal and opposite outward pressure caused by a thermonuclear furnace deep in its core. But a star has only so much fuel; when it runs out, the star's life must come to an end. When this happens the fragile equilibrium between inward and outward forces also ends. The stellar furnace flickers and goes out, and with it goes the outward force. The star is suddenly overcome by gravity. If it's small, the consequences are few; but if it's massive enough, the collapse can lead to one of astronomy's strangest phenomena. Once the collapse begins, nothing can stop it: The star falls inward on itself — slowly at first — but then in a fraction of a second it is all over. The star has become a *black hole*.

If you were to pass this region of space after the collapse, all you would see is a black circular object — visible only from the blocked light of background stars. It is perhaps a few miles across. Venturing closer you would find that it still exerts a strong gravitational pull. And if you were unfortunate enough to be pulled into it, you would never be able to pass outside again. The "surface" of a black hole is a one-way membrane that scientists call an *event horizon*. When you're inside this surface, you're cut off; there is no way you can ever again communicate with the world outside.

The only thing needed for a collapsing star to become a black hole is sufficient mass — an amount somewhere between two and six solar masses. Until a few years ago the collapse theory appeared to be the only way black holes could be produced. In 1970, however, scientists began to consider the possibility that they were also formed in the universe's early history.

By taking a close look at the initial stages of the big bang, we find that if this event was not homogeneous (that is, if matter formed in it did not expand evenly), an interesting phenomenon might have occurred. Pockets or small regions of matter may have become compressed as expansion took place around them. Some of these pockets would likely become black holes. In fact, if the theory is correct, a whole range of black holes would be created, from tiny ones smaller than viruses up to gigantic galaxy sized ones.

Speeding through a dense interstellar cloud of gas and dust, a nearly invisible small black hole leaves its mark as a trail of gravitationally disturbed material. Gas and dust — attracted by the intense force of gravity near the black hole — drain out of the known universe, becoming hot and emitting light during their infall. It is likely that the infalling material would follow a spiral path, but no one really knows. Artwork by Mark Paternostro.

Early in the history of the universe, soon after matter would have become dominant over radiation, miniblack holes may have existed in profusion. The early universe was very hot (many thousands of degrees), largely diffuse and featureless. The condensations that later would become galaxies and clusters of galaxies would have been only faint ripples in the general density of the universe. Artwork by Patty Heid.

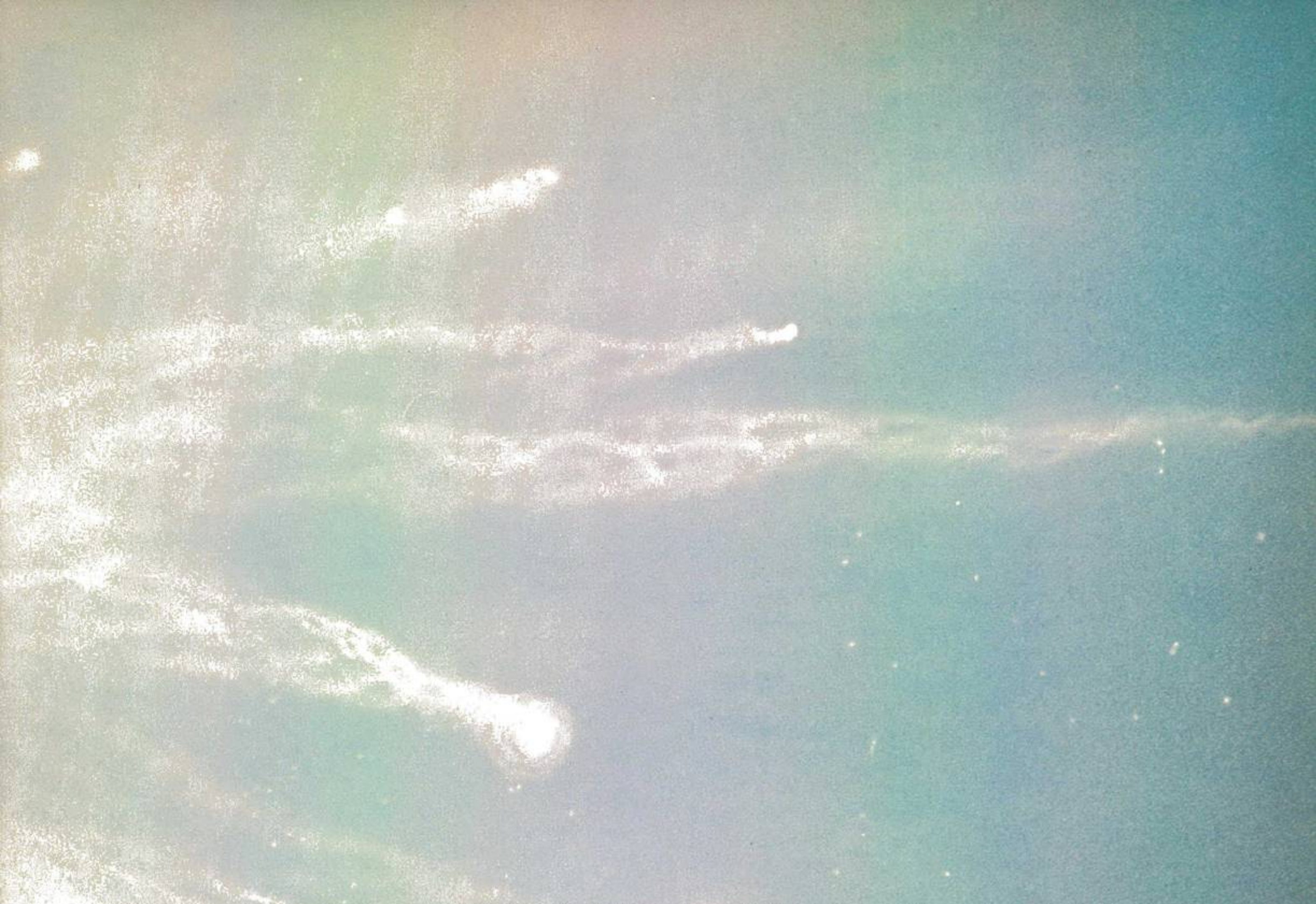
But is the theory correct? Do we have any evidence that this actually occurred? The best evidence would, of course, be visual proof that black holes (of the type described) exist. In particular, if we could find a black hole with a mass less than that of our sun, we would know it was formed in the early universe, since collapsing stars don't give rise to black holes this small. So far, however, none have been found. There is evidence, however, that the theory is viable, and strangely enough it's right in front of our noses — the galaxies. If the big bang explosion was perfectly uniform, where did the galaxies come from? A homogeneous explosion would lead to a uniformly expanding gas with no "clumping", and galaxies would not form. But obviously they did.

It seems quite possible, then, that black holes did form in the early universe. To distinguish these black holes from those formed by stellar collapse, astronomers refer to them as *primordial black holes.* The smaller ones are frequently called *miniblack holes*. These miniblack holes (assuming they exist) have some interesting properties.

If the cloud from which the black hole formed had an excess electrical charge, the resulting black hole would also be charged, having many of the traits of an atomic nucleus. The charge would attract oppositely charged particles and the result would be a *black hole atom*. If one of these atoms struck Earth, it might be possible to detect it in a bubble chamber (at least this is what some astronomers originally believed). There is, unfortunately, a slight problem when it comes to observing primordial black holes. Even though they may be no larger than an elementary particle, they possess a lot of energy. A black hole about the size of an electron would cause quite an explosion if it struck Earth.

Realizing this, Michael P. Ryan Jr. and A.A. Jackson of the Relativity Center at the University of Texas suggested in an article in **Nature** that the famous 1908 explosion in Tunguska, Russia, may have been caused by a tiny black hole. According to their calculations, a miniblack hole could have struck Earth, caused an extensive explosion, and then continued on through and passed out the other side. A similar explosion should have occurred as it exited. So far, evidence for this second explosion has not been found. In fact, Douglas Eardley of Yale University has pointed out that the theory has mathematical discrepancies. Nevertheless the idea is novel and interesting, and it does have merit.

Although a miniblack hole that might hit Earth would pass directly through it, the same is not true in the case of the sun. The sun is sufficiently mas-



HEID

sive to capture any that might hit it. If indeed it did capture a large number of these miniblack holes, they would congregate at the center, eventually forming a rather large black hole. This, of course, would have a significant effect on the sun, and a number of astronomers have suggested that this theory might be the answer to one of the outstanding solar problems of our time. According to calculations, the sun should be giving off a significant number of electrically neutral particles called neutrinos — but it isn't! Could it be that a large black hole in its core is stopping them?

Speculation is always interesting, but its dangers should also be pointed out. Just because something is possible doesn't mean it is necessarily true. It is possible that the Tunguska explosion was caused by a miniblack hole, but the probability that it actually occurred is low. Also, it is possible that our sun has a gigantic black hole in its core, but so far the idea is pure speculation. In fact, we don't yet know for sure whether or not primordial black holes even exist.

But don't let this deter your speculations — it certainly hasn't deterred scientists'. Scientific papers on primordial black holes are being published at an ever increasing rate, and many of them contain speculative predictions. In 1974, Steven W. Hawkings presented a paper (to the Quantum Gravity - Oxford Symposium) showing that black holes may be affected by quantum theory. (Quantum theory, one of the current pillars of modern physics, explains mathematically the world of atoms and molecules.) According to Hawkings, black holes may emit particles and radiation via a strange quantum process.

To see the significance of this process, let's look at the details. As we have seen, black holes absorb everything. If you shine a flashlight on one, the light is absorbed and nothing is reflected. *All* radiation is absorbed. This means that the surface temperature of a black hole should be zero degrees absolute. To understand this a little more fully, let's assume we can put a black hole in an isolated enclosure. Any radiation that is in the enclosure will soon be absorbed, and since the black hole emits nothing in return, the enclosure will reach zero degrees. But the enclosure must be in equilibrium with the surface of the black hole — meaning that the black hole must have a surface temperature of zero.

But does it? The first indication that this might not be true came when Jacob D. Bekenstein noticed that the very existence of black holes threw a curve into the basic laws of physics. The second law of thermodynamics was violated if they existed. Upon investigation, he found that black holes could (at least theoretically) be assigned a surface temperature greater than zero. But he stressed that the physical significance of this temperature should not be pushed too far; it was a mathematical convenience only.

Then came Hawkings. After careful study of Bekenstein's idea, he showed that there was more to it than Bekenstein had realized. According to his calculations, black holes do act exactly as if they have a surface temperature greater than zero; the reason is the quantum process.

One way of picturing this process is to see it as a type of *pair production* (which refers to the generation of two oppositely charged particles of equal mass) that occurs just outside the event horizon. One of the two particles falls into the black hole, and the other escapes into space. The result is a black hole that appears to emit particles and radiation. It would, in most respects, act just like any other object at a temperature above zero.

But if it radiates, it loses energy. And if it loses energy, it also loses mass — and we know that the radius of the black hole depends on its mass. This means, then, that the surface area of the black hole decreases. But there seems to be a contradiction here. According to a well known theorem — one of the four Black Hole Dynamic Theorems formulated by Hawkings — black holes can't decrease in surface area. They can join and grow, but they can never get smaller. Actually, this theorem was formulated and proved before it was known that quantum theory had any effect on black holes. It applies therefore only to what are called "classical black holes". When quantum effects are taken into consideration, black holes *can* decrease in size.

The speed of decrease depends on their mass, which also determines their surface temperature. Consider, for example, a black hole with a mass equal to that of our sun. A simple calculation shows that its surface temperature would be less than one degree absolute. But empty space is hotter than this (the microwave background gives space a temperature of approximately 2.7 degrees absolute); we would never even notice it wasn't zero. Now let's consider a black hole with a mass of 10^{25} grams. A black hole of this mass would have a temperature of 10 degrees above absolute zero. But one with a mass of 10^{15} grams would have a temperature of 10^{11} degrees — quite a jump! In other words, large black holes have surface temperatures hardly different from zero; but as mass decreases, surface temperatures skyrocket. This means that miniblack holes are extremely hot!

This in turn has an interesting consequence. We know that the higher the temperature of an object, the more it radiates. In the case of a black hole, this means that the smaller it is, the faster it decreases in size. In fact, according to recent calculations, in the last few seconds of its life both the energy output and the surface temperature of a miniblack hole soar. To a distant observer it literally appears to explode.

Indeed, all black holes eventually end their life in an explosion. Large ones last almost indefinitely — but again, it's a different story for the miniblack holes. One that is formed with an initial mass of 10^{5} grams will only last about 10^{-12} seconds. Even if its initial mass is 10^{10} grams, it will last only three seconds. From here on up, however, things look a little better. One with an initial mass of 10^{15} grams will last about 10 billion years — roughly the length of time our universe has been around. This means that miniblack holes with a mass of 10^{15} grams are exploding right now. It should also be pointed out that all black holes smaller than this have already exploded and dissipated into space.

Let's look at this 10^{15} gram black hole. First of all, how large is an object of average density with mass of 10^{15} grams? As a rough estimate, we could say a small moon about one mile across would have this mass. If an equivalent mass were compressed to a black hole in the early universe, however, it would hardly be larger than an electron. It now has a surface temperature greater than 10^{11} degrees and is evaporating rapidly. Particles of many different types are being emitted from it. And in the last moments of its life — which is right about now — it explodes, releasing energy equivalent to a million megaton hydrogen bomb.

Obviously, this is a lot of energy. Is there any possibility one of these black holes could explode close to Earth? If it did, it would certainly do considerable damage. Fortunately, the probability that one will explode nearby is quite low. Hawkings has shown that approximately one such explosion per month should occur in a sphere of about three light-years' radius around us.

Getting back to the explosion itself, let's consider the following interesting question: What happens to the singularity when the black hole explodes? Is it left in space, or does it disappear too? If it's still there, it is now without an event horizon — it is "naked"! Physicists are not enthusiastic about such a possibility. If there is a naked singularity left after the explosion, they have some serious problems to face.

Scientists have for years considered the possibility of naked singularities, but they weren't thinking about exploding black holes. They were considering those generated by collapsing stars. If a star is spinning sufficiently fast as it collapses, it might end as a naked singularity — and then again it might not. Scientists are just not certain. The only thing that is certain is that they hope such freaks of nature don't exist. A naked singularity would be a skeleton in their closet — an oddity that defies one of the basic principles of physics: the principle of causality. According to this principle, every effect has a cause. In simpler language, if we know the state of a system at a particular time, we can predict what will happen to it at a later time. With naked singularities this is no longer true.

Up to this point we have concentrated mainly on the tiny primordial black holes, but as we mentioned earlier a whole array of black holes would be generated — from tiny ones right up to exceedingly large ones, 10^7 times as massive as our sun. Some of these latter ones might eventually have captured entire galaxies and may now be residing at their core, gradually eating away at them. As they pull in nearby stars, they grow larger and more powerful until finally they consume the entire galaxy.

The mysterious quasars may also be black holes in disguise. Many interesting black hole models of enigmatic objects have been put forward. A number of astronomers have even suggested that rather than black holes, they may be white holes. White holes can be thought of as the inverse of black holes; instead of matter pouring into them, it pours out. Quasars do appear to have activity of this type associated with them, so perhaps a white hole model is better (see "Black Holes, White Holes and Wormholes", ASTRONOMY, November 1976).

Again, we come to the same problem: Is there any evidence for these extremely massive black holes? Surely if they existed we would be able to detect them, considering how large they would have to be. The evidence is indirect at best. For years it has been known that the Virgo galaxy cluster and several other clusters have insufficient mass to be gravitationally bound. Yet they *do* appear to be bound. Could there be some mass in these systems that we cannot see — for example, in the form of giant black holes? Sidney van den Bergh of David Dunlap Observatory has considered this possibility. Realizing that if large black holes did exist in a cluster, they would no doubt cause severe distortions in some of the galaxies, he made a thorough search of the Virgo cluster. Several of the galaxies were distorted, but after careful study Van den Bergh concluded it was unlikely that this was caused by black holes. To supply the missing mass they would have to be gigantic and, as far as he was concerned, there just wasn't sufficient evidence. Similar studies of other clusters have yielded the same conclusion.

Scientists are still searching for their first primordial black hole. The discovery may be just around the corner; they now have several good candidates for stellar collapse black holes. One of them (Cygnus X-1) is firmly believed by many astronomers to be a black hole.

Barry Parker is an associate professor of physics and astronomy at Idaho State University, where he has taught courses in descriptive astronomy, astrophysics, cosmology and astrophotography. His main interests are black holes and cosmology; he is presently writing a popular level book on the latter.

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Cold Nights, Bright Planets

Various members of the solar system put on a good show during February. Saturn is at opposition at the beginning of February, while Venus reaches its greatest brilliancy at month's end. Both planets are thus at their very brightest, and are easily located; Jupiter also is still in a good position for observing. In addition, the minor planet Pallas reaches opposition, and Uranus is occulted by the moon on the 10th. Thus, many types of projects for all kinds of observers are featured this month.

February Satellites of Jupiter
10:00 p.m. EST, 7:00 p.m. PST

1	43120	• • ••●	16	34012	••● • •
2	43012	• •● • •	17	41023	• •●• •
3	4103	• •● •	18	42013	• • ● • •
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5	4023	• •● • •	20	40132	• ●•• •
6	4102	• • ● •	21	4320	• ••●
7	3201	• •• ●•	22	43210	•• ••●
8	31204	• ● •	23	34012	• • ● • •
9	30124	• ●• • •	24	10342	• ●•••
10	10234	• ●•• •	25	20134	• ● • ••
11	20134	• ● • • •	26	12034	• •● • •
12	10234	•●• • •	27	01324	●••• •
13	024	● • •	28	3204	• • ● •
14	32014	• • ●• •	29		●
15	32104	• ••●•	30		●

The four major satellites of Jupiter orbit the giant planet in periods ranging from just under 2 days to 17 days. They can be seen to change position from night to night. Sometimes their motions become evident after only a few minutes' observation. Only a small telescope is required to detect all four of the satellites and several can frequently be seen in rigidly held binoculars. This table shows the approximate positions of the moons at about 11 p.m. (EST) on the evenings indicated. First column on the left shows the date. Second column of numbers identifies the moons and their positions relative to Jupiter's disk. (1=Io; 2=Europa; 3=Ganymede; 4=Callisto, and 0=Jupiter's disk.) The third column approximates a telescopic view of the satellites' positions. The orientation of the satellites is shown inverted as seen in a standard astronomical telescope.

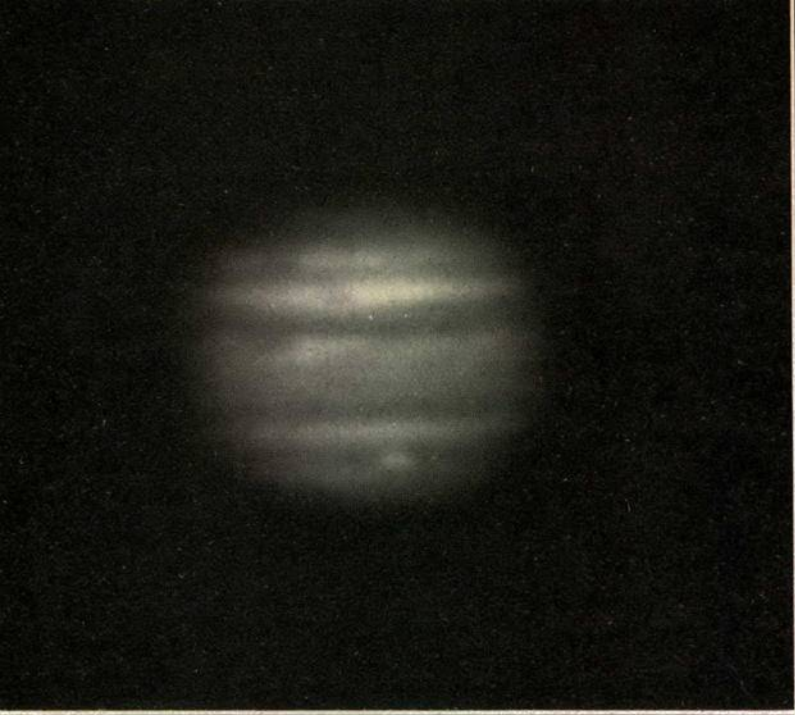
Venus

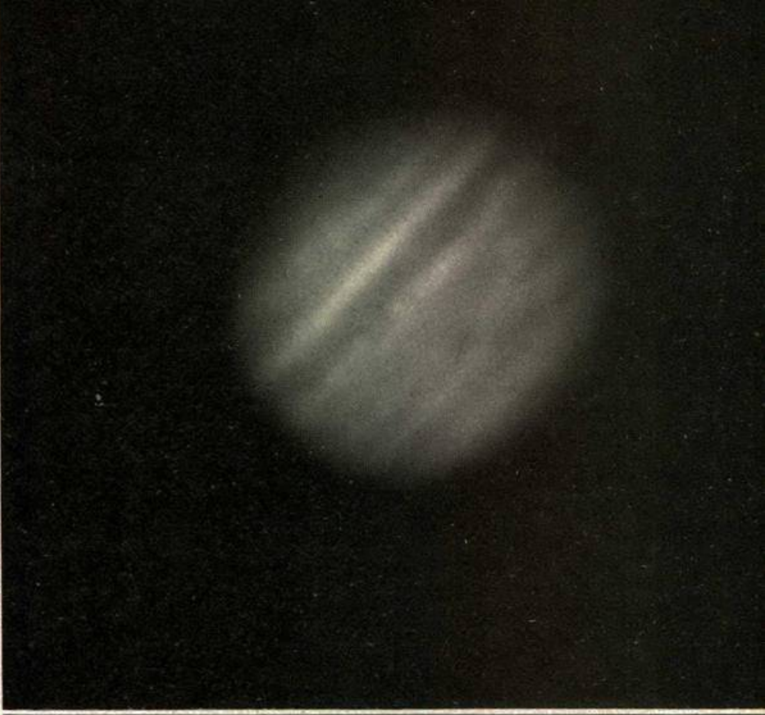
The planet Venus, still glittering brightly in the evening sky after sunset, reaches greatest brilliancy on the 28th, when its magnitude is -4.3. Setting almost four hours after the sun, Venus' phase gradually decreases during February from half to crescent, while its angular diameter grows from 26.5 to 38.2 seconds of arc. As the planet approaches inferior conjunction, it moves closer to Earth; its distance from us decreases during the month from almost 59 million (94 million) to 40 million miles (64 million kilometers).

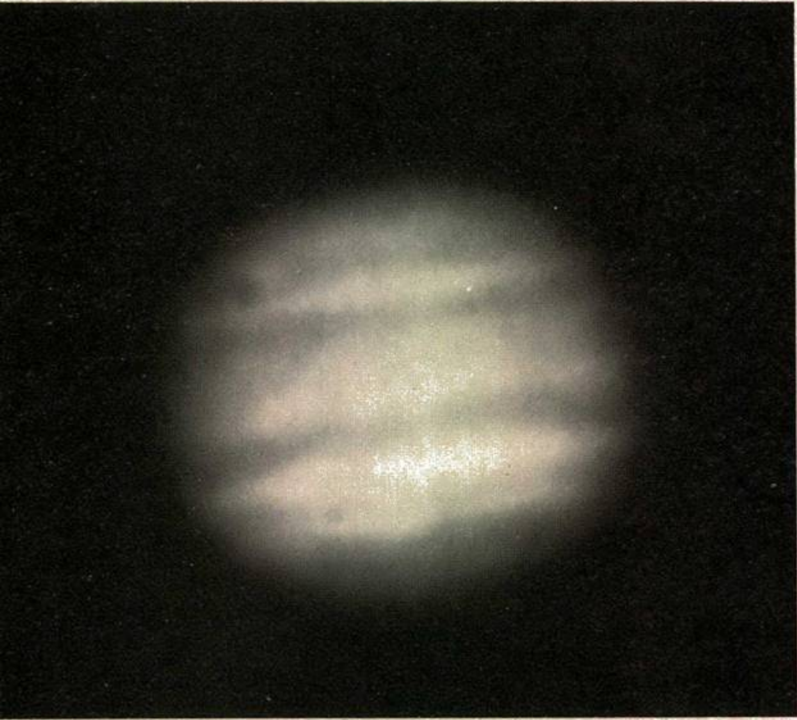
Jupiter

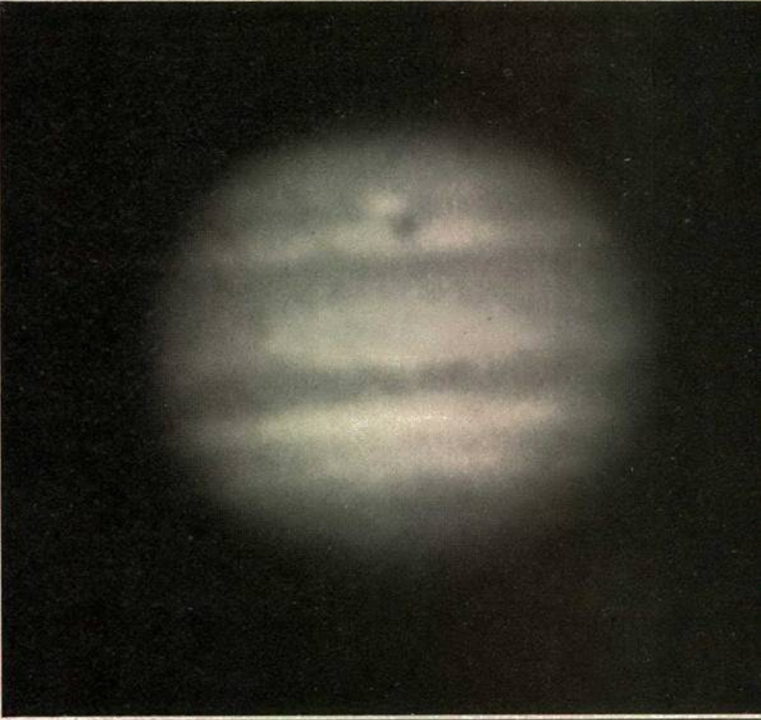
The giant planet moves back into Taurus during February and can be easily located west of Aldebaran, which it greatly outshines at magnitude -2.0. Available for evening observation, Jupiter sets shortly after midnight. Now moving away from Earth, the planet's apparent diameter decreases from 38.5 to 35.2 seconds of arc during the month, as its distance increases from 443 million (713 million) to 484 million miles (778 million kilometers).

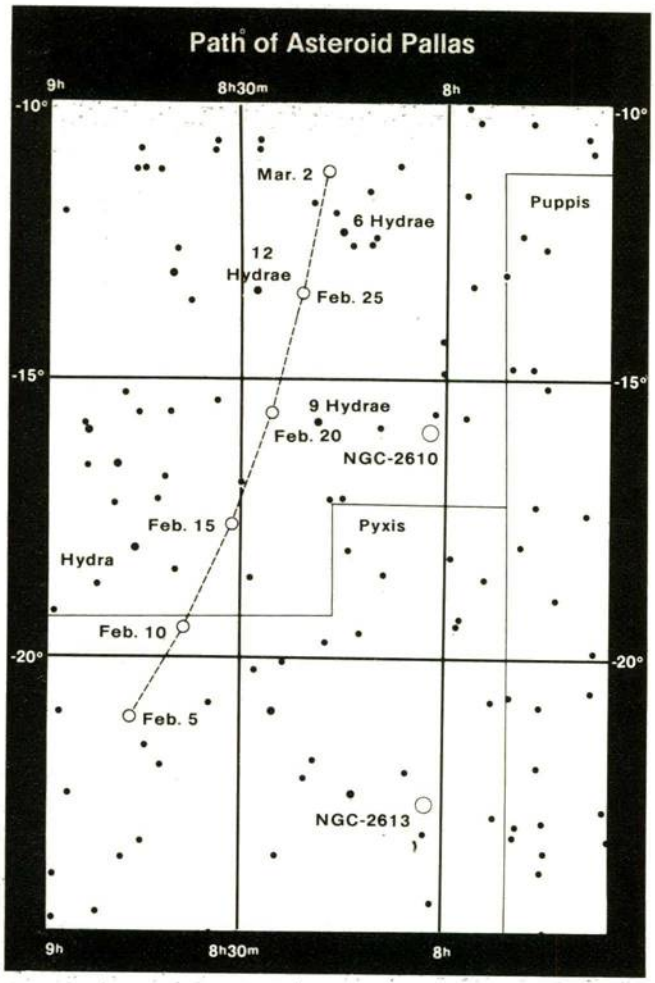
The planets, when near opposition, are favorite subjects for photography; a few samples are reproduced on the opposite page. Top left: The disappearance of the Great Red Spot almost gives Jupiter the appearance of incompleteness, but superbly detailed cloud bands in this photo more than compensate. This is a two second exposure on SO-410 film, made through an eight inch Schmidt-Cassegrain telescope at f/138. Top right: This one second exposure on H&W film was obtained through a 14 inch Schmidt-Cassegrain at f/98. Photographs by Steve Reed. Center: These two photos of Jupiter show the shadow of Europa in transit across the planet's disk. Both are two second exposures on Pan-X film, made with a home built eight inch f/5 reflector. Photographs by Lester Yuill. Bottom: This finely detailed portrait of Saturn is a four second exposure on Tri-X film, made through a home built 10 inch Newtonian reflector at f/185. Photograph by E. Ken Owen.











As briefly noted last month, Jupiter's Great Red Spot has been extremely faint at this opposition. This is not a unique state of affairs; the Red Spot has faded almost to invisibility in other years also. Observers might wish to keep an eye on the planet and note when the spot begins darkening again.

Saturn

Saturn reaches opposition on Feb. 2, at which time its magnitude will be 0.0 and its distance from Earth will be 758 million miles (1,218 million kilometers). The planet is located in the constellation Cancer. Further details on observing can be found in this month's Gazer's Gazette.

Mercury, Mars

At the end of January, Mercury was at greatest western elongation; therefore, except for the first few days of the month, it is not available for observing during February. Mars is too close to the sun to be easily observed during the month.

Asteroids

On Feb. 10, the minor planet Pallas reaches opposition near the boundary separating the constellations Pyxis and Hydra. This extreme southerly declination is due to Pallas' high orbital eccentricity. After opposition, Pallas will move rapidly northward through Hydra toward the ecliptic. Its magnitude on Feb. 10 will be +6.7, and its distance from Earth on that date will be 117 million miles (188 million kilmeters). For Pallas' location during February, check the map on the left.

Ceres will be at opposition on March 24. During February, it is located in Virgo; from the 10th to the 15th, it can easily be spotted less than a degree away from third magnitude Epsilon Virginis. Its magnitude during February slowly increases from +6.9 to +6.6.

Vesta, just past opposition, is still located in Gemini. At the beginning of the month, it can be found just west of fifth magnitude Omega Geminorum. At magnitude +6.7 during most of the month, Vesta continues retrograde motion until March 1.

All three asteroids can be seen easily with binoculars. An interesting project for both observers and astrophotographers is to follow any of these asteroid's motions from day to day. Photographers should use a telephoto lens for best results. Photo sequences demonstrating an asteroid's motion against the star background can be submitted for possible publication in ASTRONOMY.

Occultation of Uranus

On the morning of Feb. 10, our moon will occult the planet Uranus. This occultation will be visible from a large section of North America; in the United States, observers who live northwest of a line from northern Idaho to southeastern Georgia will be able to watch this event. On the other side of this line, the moon either will not have risen or will miss occulting the planet.

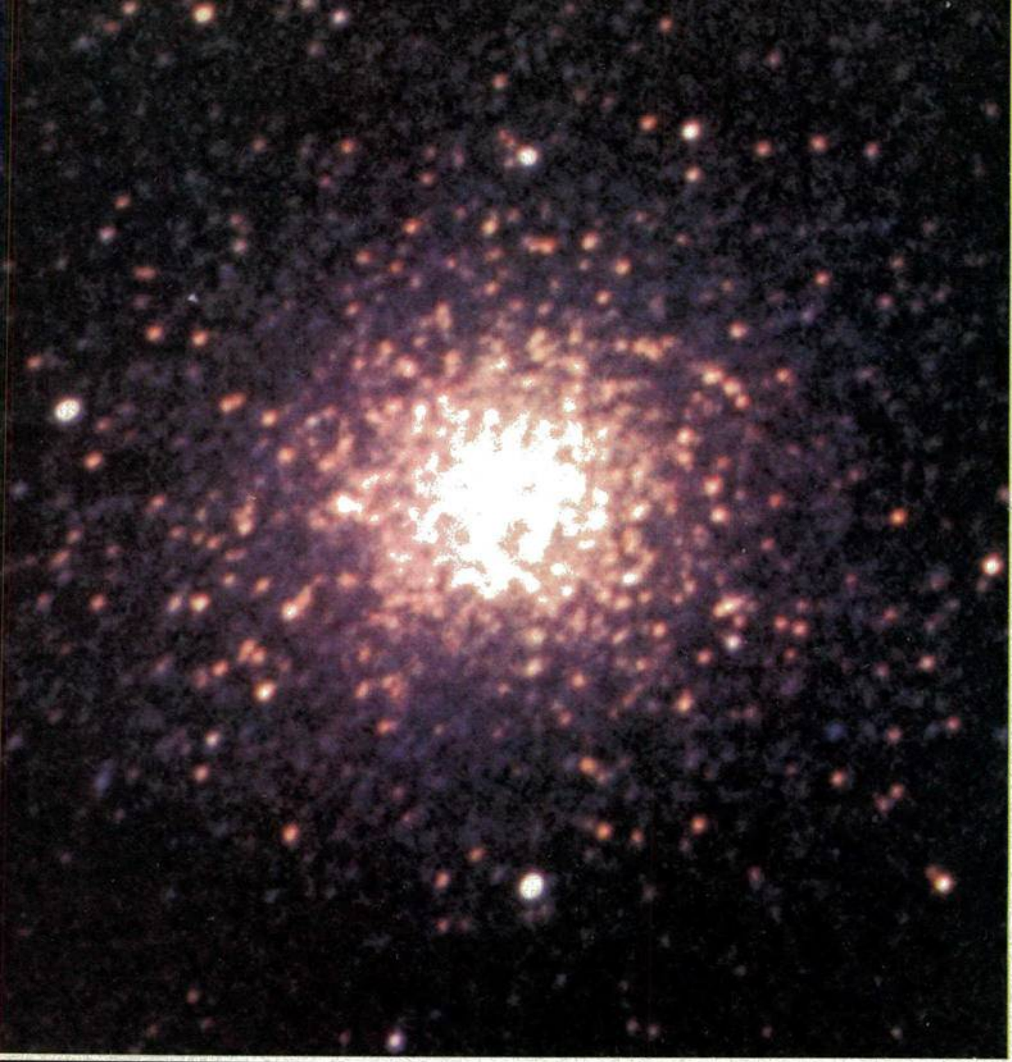
Since the moon is in last quarter phase on the 10th, Uranus will emerge from occultation on the moon's dark side. The point and time of emersion will depend, to a great extent, on the observer's latitude and longitude. Emersion will occur at about 5:08 a.m. from the longitude of New York City, and about 3:44 a.m. from the longitude of Chicago. Reports and photographs of this event are welcome at ASTRONOMY.

Solar Eclipse Report

Poor weather conditions in southern Australia on Oct. 23, 1976 prevented many observers — some of whom had traveled thousands of miles — from seeing the total eclipse of the sun that took place on that date. ASTRONOMY's official photographic representatives, Brad Wallis and Robert Provin, were almost clouded out themselves, but managed to obtain some photographs when conditions momentarily improved. Their report follows:

"Our eclipse site near Mansfield [about 150 kilometers (93 miles) northeast of Melbourne in

The Oct. 23, 1976 total eclipse of the sun, visible from Australia, generated such exciting photographs as the one reproduced here. Taken through a thin cloud layer that partly obscures the corona, the photo clearly shows bright prominences on the sun's limb. ASTRONOMY Magazine Australia Expedition Photograph by Brad Wallis and Robert Provin, copyright© 1976 by AstroMedia Corp.



Victoria] was located in a valley surrounding Lake Eildon. This site was selected because it was expected to possess a minimal amount of late afternoon thermal clouds. On Oct. 22 and 24 this valley was practically cloudless at the time of the eclipse (4:42 p.m. AEST). But on the day of the eclipse, a front moved across Victoria from the west and produced a multilayer cloud cover that made nearly all places along the Australian central line virtually useless.

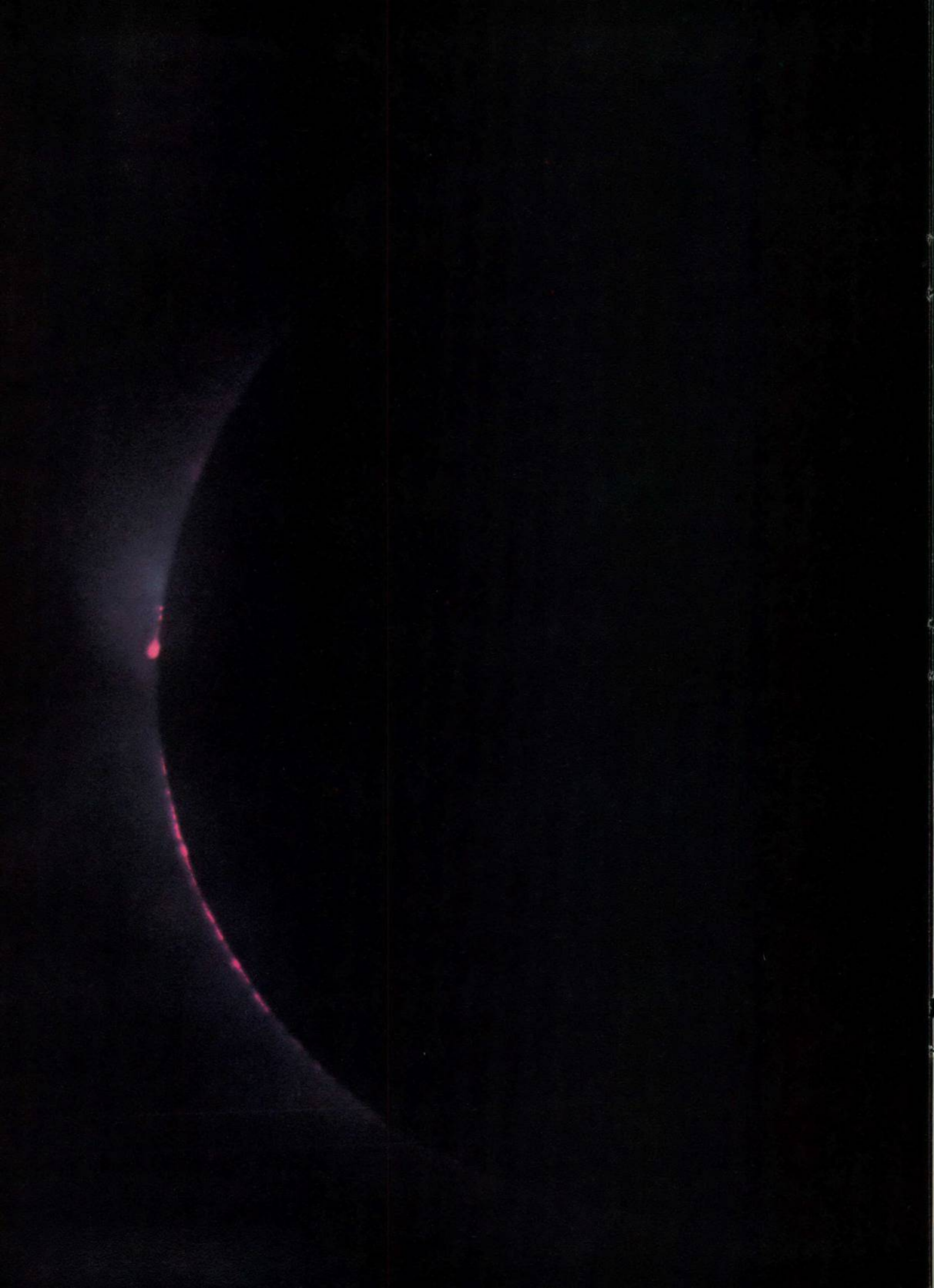
"We chose a conical hill (the southern member of a formation known as the Paps) and drove to its summit where we had an unobstructed view of the western horizon (hoping for a view of the incoming Earth's shadow). As totality neared, the cloud cover grew heavier and our hopes for seeing this awesome spectacle faded rapidly. Our surrounding scenery darkened quickly, cockatoos and kookaburras screeched and took flight as night fell. Then, about 30 seconds into totality, the lower cloud level parted and we could see the sun's corona and several large prominences shining through a layer of cirrus clouds.

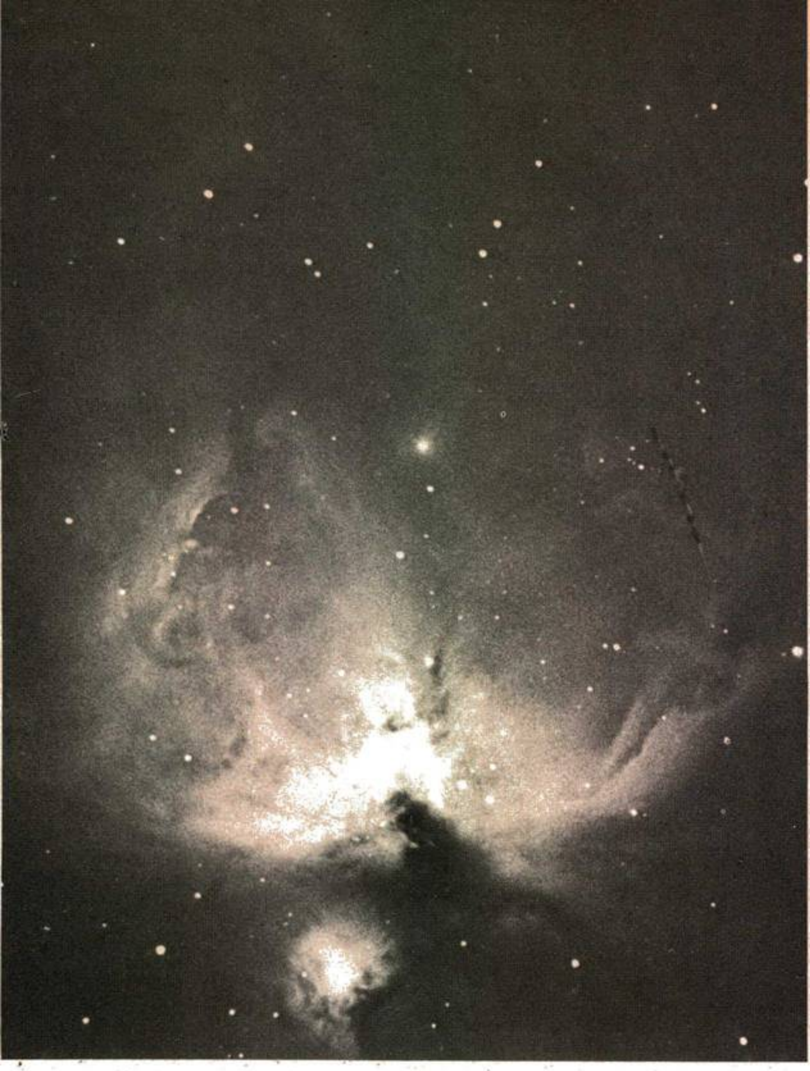
"Within 10 minutes of the end of totality, the sun was totally obscured and did not appear from behind the clouds again that afternoon. The heavy cirrus layer diffused the sun's image and dimmed the light from the sun's outer atmosphere by a factor of 10 to 15."

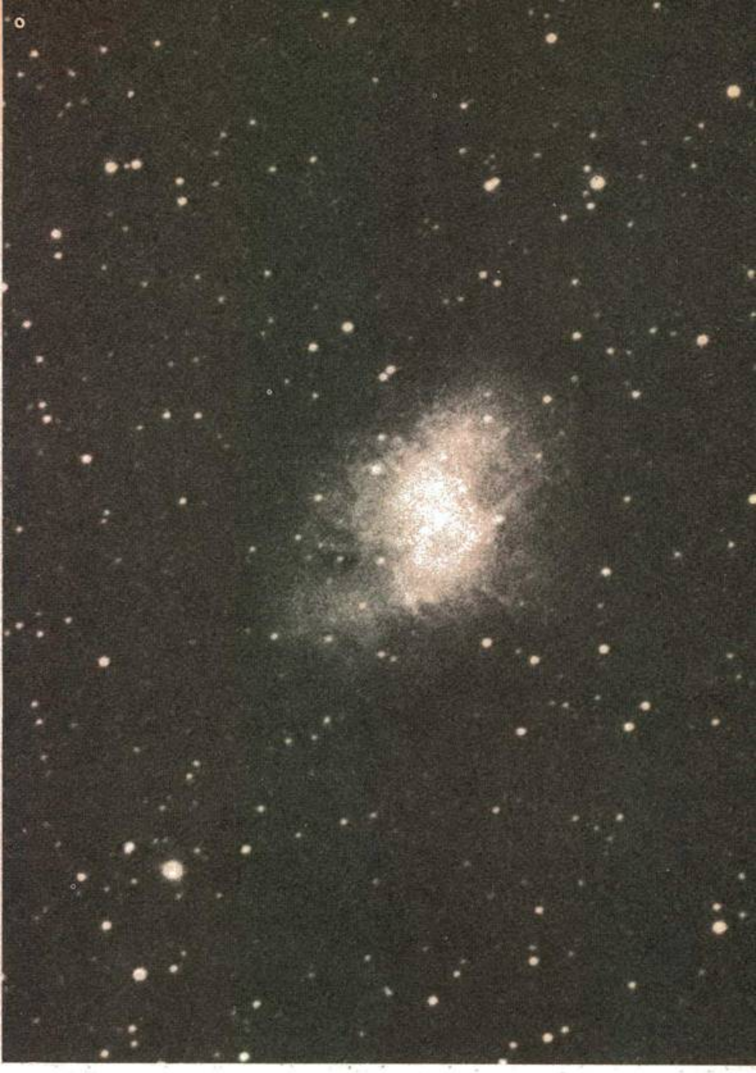
Above left: Omega Centauri is the largest and brightest globular cluster in the entire sky. Because of its far southern declination, however, it goes unobserved by many northern observers. Much more glorious than M-13 in Hercules, Omega Centauri has an integrated magnitude of 4.5 and is one of the nearest globular clusters to the sun. This photograph is a 20 minute exposure on GAF 500 film, obtained through an eight inch Schmidt-Cassegrain telescope at f/5. Photograph by David Healy. Top right: This finely detailed photograph of Jupiter reveals multicolored cloud belts and zones. Taken on Oct. 11, 1976, this is a 2.5 second exposure on Kodachrome 64 film; a 16 inch Cave Newtonian reflector at f/5 was used. Photograph by Andrew W. Steinbrecher. Bottom right: Saturn is more distant and more difficult to photograph satisfactorily than Jupiter; and it does not reveal as much detail. The beauty of the rings, however, makes the planet a prime target. A 14 inch Schmidt-Cassegrain telescope at f/98 was used to obtain this four second exposure on High Speed Ektachrome, on Oct. 24, 1976. Photograph by Steve Reed. Opposite, top: This beautiful picture of the nearly full moon is a first attempt at astrophotography; it captures the moon's true color and is superbly detailed. Kodachrome 25 film was used to obtain this exposure through an eight inch Schmidt-Cassegrain telescope. Photograph by Larry Rinker. Opposite, bottom: An open cluster in Puppis, M-46 is very rich in faint stars arranged spherically. Because it lies so far south, atmospheric conditions often prevent its observation; the slightest haze or turbulence can blot out its faint stars completely. Under good conditions, however, it presents a fine sight. The tiny planetary nebula NGC-2438 is not part of the cluster, but is actually much nearer. It appears redder to the camera than it does to the naked eye. This is a 45 minute exposure on GAF 500 film, made with an eight inch Schmidt-Cassegrain telescope at f/5. Photograph by David Healy.

Several of Brad's and Bob's photos appear on these pages.

The extent of the cloud cover over Australia is







Opposite: Prominences burst from the limb of the sun, hidden from sight by the totally eclipsing lunar disk, in this closeup of a photo obtained from Australia on Oct. 23, 1976. ASTRONOMY Magazine Australia Expedition Photograph by Brad Wallis and Robert Provin, copyright© 1976 by AstroMedia Corp. Above left: this is a 15 minute exposure on 103aF film of M-42 (the Orion nebula). A 10 inch home built Newtonian at f/6.15 was used. During printmaking, dodging techniques were employed in the central regions of the nebula. Photograph by E. Ken Owen. Above right: This 30 minute exposure on 103aE film of the Crab nebula (M-1) was obtained through an eight inch Schmidt-Cassegrain at f/10. Photograph by Leo C. Henzl Jr.

Satellite Shadows on Jupiter

Date	Satellite	Transit Begins (EST)	Transit Ends (EST)
Feb. 3-4	2	11:52 p.m.	2:21 a.m.
6	1	9:33 p.m.	11:43 p.m.
8	1	4:02 p.m.	6:12 p.m.
13-14	1	11:29 p.m.	1:39 a.m.
14	2	3:47 p.m.	6:16 p.m.
15	1	5:58 p.m.	8:08 p.m.
21	2	6:23 p.m.	8:52 p.m.
22	1	7:53 p.m.	10:04 p.m.
28	2	8:59 p.m.	11:28 p.m.

1 =Io
2 =Europa
3 =Ganymede
4 =Callisto

indicated by the submission of only one additional eclipse report at the time of this writing. Michael Barrett of Chicago, Ill. writes:

"During the pretotal partial phases, thin clouds drifted in front of the sun, although I could still see the sun through them. There were also patches of blue. As the eclipse progressed, the light grew dimmer and a cool breeze began to blow. My shadow was sharp on the highway against the amber colored light. The birds sang as they do at sunset.

"Someone fired a gun in the distance at the instant totality began. I looked through my camera's viewfinder, which was connected to my 2.4 inch telescope. I saw Baily's Beads. . . . When the corona came into view, through my telescope, all I could see was the innermost part of it, and that was very faint. The corona could easily be seen with the naked eye through the thin clouds. . . . Antares was seen high in the sky through an opening in the clouds.

"It was quite light during totality. I was able to easily read the settings on my camera. The twilight was equivalent to the twilight about 20 minutes after sunset. . . . I glanced up at the sun only to see Baily's Beads reappearing.

"My sister stayed behind at the hotel. She said she did not care to see the eclipse — probably because she was distraught over not being able to hold a koala bear."

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I am not only pleased but rather astounded by the optical perfection of your Research-Grade eyepieces.
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Donald J. Smith Shadeyside, Ohio

I am now using a Research-Grade Erfle 20mm purchased from your firm recently on my Celestron 14 and find the ocular is all that you claim and more. It reveals delicate color contrasts on Saturn superbly, as well as globular clusters, nebulae, and double stars.
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I appreciate the fast shipment of the 20mm Research-Grade Erfle, which was in my hands 4 days after I mailed the order! I would also like to say that the eyepiece is the finest I have ever used, borrowed or seen, and I have seen many in the 15 years I have been an amateur. In the future I intend to convert my battery of eyepieces to Meade Research-Grade orthoscopics, the sooner the better.
Jim Schultz Lyons, Colorado

Let me mention how pleased I am with your products and the very prompt service I have received. I am especially excited with your Research-Grade 20mm Erfle. Its incredible field of view and flatness of field make it perfect for my variable star work. It is truly breathtaking with deep-sky objects. The real surprise came when coupled with your Research-Grade 2X Telenegative Amplifier . . .truly a fine optical achievement.
James L. Ferreira Fremont, California

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Set of any 4 Orthoscopics, with case	112.50 ppd.
Set of any 4 Orthoscopics plus Erfle 20mm, with case	137.50 ppd.
Full set of 5 Orthoscopics plus Erfle 20mm, with case	165.00 ppd.

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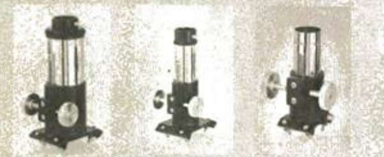

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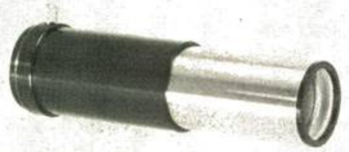

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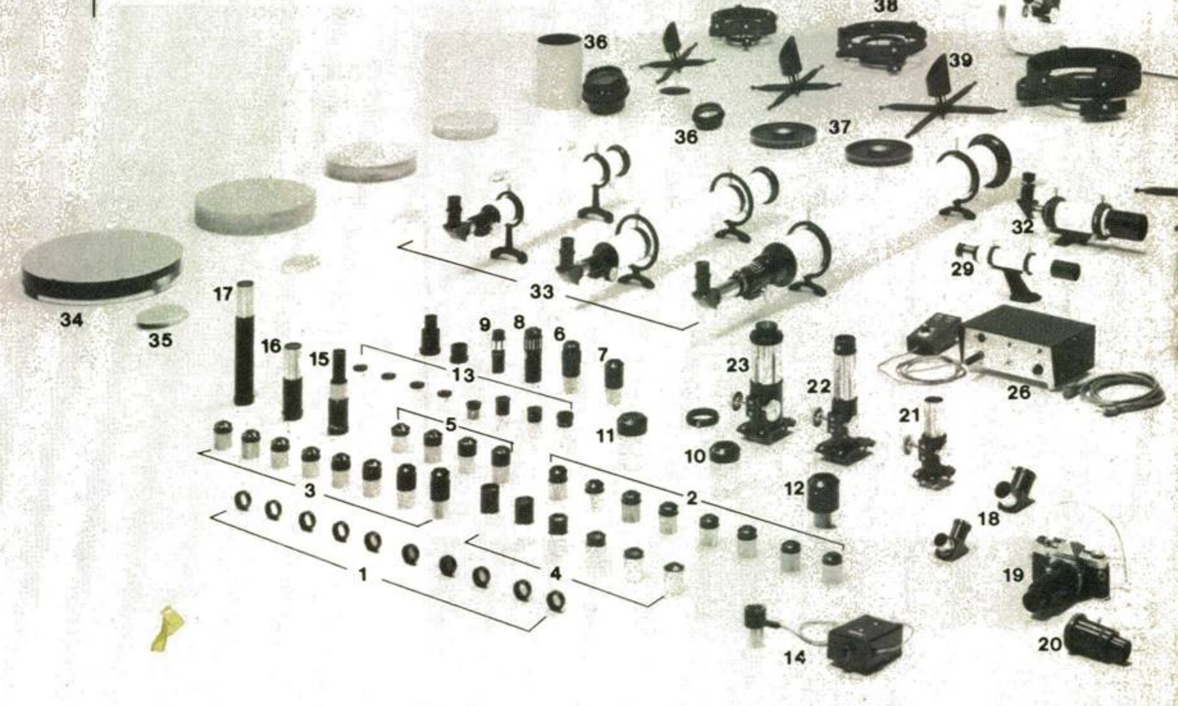

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GAZER'S GAZETTE

Observing Saturn

by
Henry J. Phillips

There are a few celestial objects to which no photograph or description can possibly do justice; the finest of these is undoubtedly Saturn. True, you can find good observatory pictures as well as rapturous paragraphs describing the planet's beauty in virtually any astronomy book, but there's no substitute for the view through the telescope.

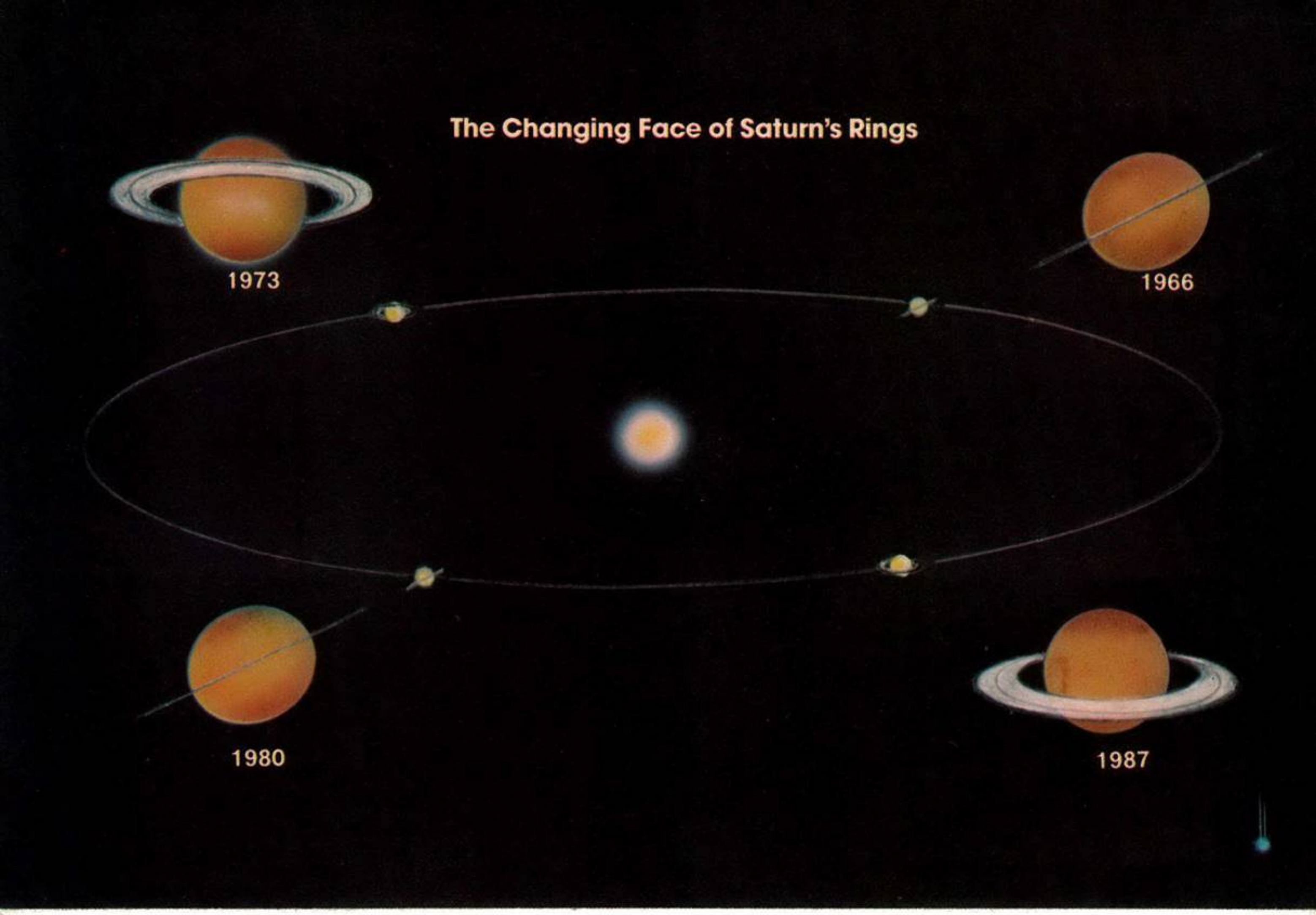
Many people who have never seen Saturn find it difficult to imagine that such a splendid object can actually exist, but even a glance through a small refractor is enough to reveal Saturn's special glory and sweep away all doubts. Mars may be more intriguing and Jupiter more interesting, but Saturn is certainly the most "perfect" of the planets.

There's no denying Saturn's beauty, but you'll soon discover after your first thrilling glance that Saturn requires much closer scrutiny than either Mars or Jupiter. Because Saturn is so remote, many of the planet's finer details are difficult to see in small or medium sized telescopes, and even large instruments show that Saturn doesn't have the vivid, everchanging cloud belts that Jupiter exhibits. It's easy to conclude that, if it weren't for the rings, observing Saturn would be rather dull. Fortunately, we *do* have the rings — more than ample compensation for whatever else the planet may lack.

The main reason for Saturn's scarcity of detail is its distance. On the average, the planet is about 887 million miles (1,427 million kilometers) from the sun. Even at this year's opposition on Feb. 2 — the time at which Saturn and Earth are closest together — Saturn will be 758 million miles (1,218 million kilometers) away. This distance makes Saturn almost twice as far from Earth as is Jupiter, so even if Saturn were just as detailed as Jupiter, distance alone would be enough to make the ringed planet more difficult to observe. As it is, Saturn is the faintest of the naked eye planets (although, of course, it's still quite bright). At its very best, Saturn is certainly bright enough to outshine most of the stars, but is fainter than Venus, Mars, Jupiter and even Mercury at their brightest.

Saturn is a gas giant, similar to Jupiter in "construction" but slightly smaller. Saturn is the most *oblate* (flattened at the poles) of all the planets — even more so than Jupiter. Its equatorial diameter is about 75,000 miles (121,000km), whereas its polar diameter is only about 68,000 miles (108,000km). This oblateness is most obvious when Earth passes through the plane of Saturn's equator (every 15 years or so); the planet looks a little "squashed".

Because it's so much farther from the sun than


The Changing Face of Saturn's Rings
1973
1966
1980
1987

Saturn's polar axis is inclined to its orbit by an angle of almost 27 degrees; we therefore see Saturn and its rings at different angles during its 29-1/2 year revolution around the sun. In 1966 (top, right), Earth passed through Saturn's equatorial plane and the rings were seen edge-on. After gradually opening out, the southern face of the rings was fully displayed in 1973 (bottom, right). By 1980 (bottom, left), the rings will be edge-on again, and the northern face will be visible on 1987 (top, left). Artwork by Mark Paternostro.

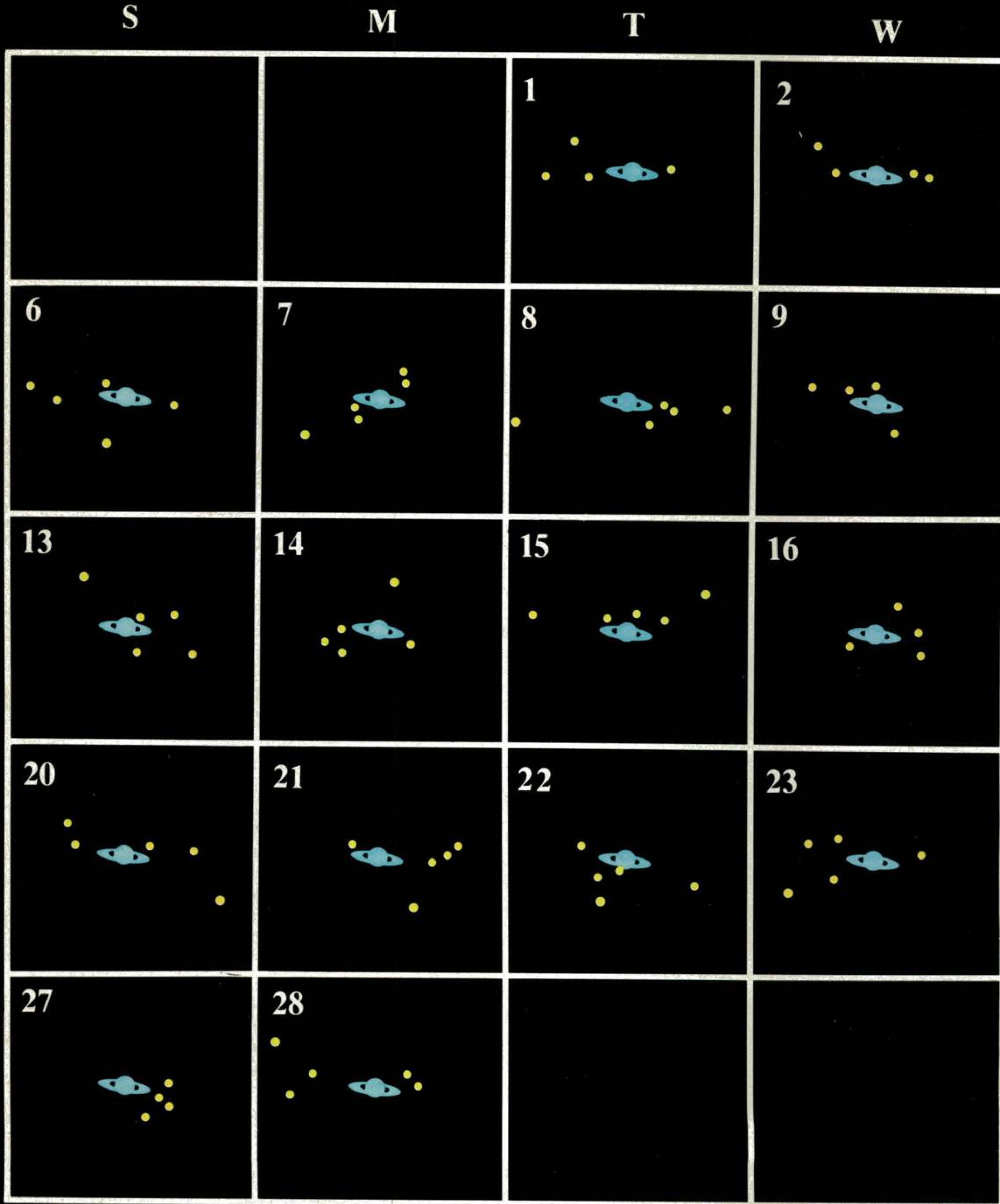
Jupiter, Saturn is colder; the temperature at the top of its atmosphere is around -250 degrees Fahrenheit. Its atmosphere is therefore much less active — it's "quieter" — than Jupiter's. Most of the transient phenomena that help make Jupiter endlessly fascinating simply aren't present on Saturn, and what permanent markings *do* exist are a lot harder to find. Saturn has cloud belts, but they're not nearly as prominent as Jupiter's. The easiest to spot is a bright equatorial zone, and you'll need at least a six inch telescope to see it easily, as well as to find the darker polar regions. A four or five inch telescope will show these variations in brightness if you know what you're looking for, watch carefully, and have a lot of patience; smaller scopes can make out no surface detail at all.

Saturn has no permanent features similar to Jupiter's Great Red Spot; in fact, dark spots have never been detected in Saturn's atmosphere. However, an occasional white or light colored spot will arise and may last a week or two before disappearing. Such spots are rare enough that they're named after their discoverers. If you'd like your name to be given to Saturn's next spot, you'll need a telescope of at least 12 inches aperture, and probably more. Only such a large instrument can show enough detail on the planet's disk for such features as spots to be readily seen. If your scope is big enough, keep an eye on Saturn; after all, there's no telling when the next white spot will be born.

Until recently, Saturn's undetailed atmosphere prevented accurate determinations of the planet's rotation period. That's why the discovery and observation of spots was so important; by an accurate measurement of the amount of time they required to circle the planet, the length of Saturn's day could be calculated. The best current figures are 10 hours 14 minutes at the equator, and 10 hours 38 minutes at higher latitudes. (As with Jupiter, different parts of Saturn's cloud cover rotate at different rates of speed.)

But when "all's said and done", most people don't observe Saturn to search for detail on its disk; they want to look at the rings — and why not? They're simply glorious. Saturn's rings rescue the planet from being a dull, seldom observed member of the sun's family, and transform it into the most breathtaking sight in the sky. Certainly they increase Saturn's brightness. When the rings are seen

Saturn's Moons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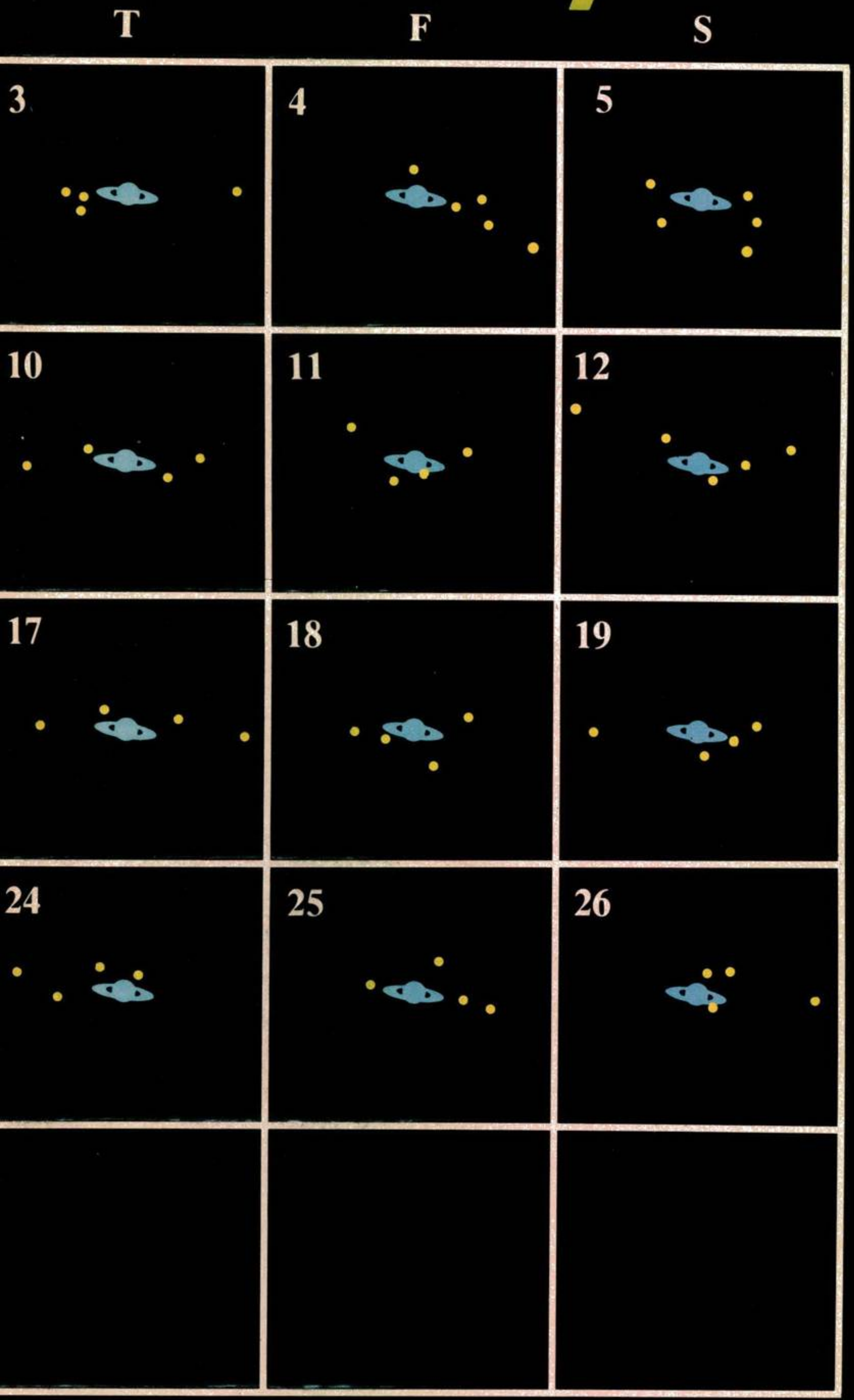


This calendar, similar to the "February Satellites of Jupiter" chart in Sky Almanac, indicates the relative positions of Saturn's moons for every day in the month, at midnight EST and 9:00 p.m. PST.

As with the four bright satellites of Jupiter, most of Saturn's moons orbit the planet in the equatorial plane. Jupiter has a nearly vertical orientation in its orbit, such that the moons appear to move in a straight line from one side of the planet to the other. Saturn, however, has an axial tilt of almost 27 degrees. When one of the planet's polar regions is visible — as this year — the moons can be seen "above" the planet as they move behind it. Such phenomena as transits, occultations and satellite shadows can be seen only when Earth passes through Saturn's equatorial plane, about every 15 years.

The satellites included in these telescopic views are Enceladus, Tethys, Dione, Rhea and Titan. Because of the scale on which this calendar is reproduced, the extreme eastern and western edges of Titan's orbit could not be fitted in. For observers interested in seeing Titan when it is at greatest eastern or western elongation, the dates and times of such phenomena are:

Greatest western elongation:
Feb. 10, 6:36 p.m.
Feb. 26, 4:06 p.m.
Greatest eastern elongation:
Feb. 3, 2:48 a.m.
Feb. 19, 12:18 a.m.

Of the other moons, Rhea, Tethys and Dione can be spotted easily in a four inch telescope. Enceladus, although dim and very close to Saturn, is included here for those owners of large aperture instruments who feel up to the challenge of finding it.

In addition, a sixth moon, Iapetus, is visible in a four inch telescope when it's at greatest western elongation (see text for details). Iapetus will reach this point on its orbit on Feb. 2 (the date of Saturn's opposition) at 12:12 a.m. On this date, Iapetus will be a 10th magnitude object, 41 minutes of arc west of Saturn's disk.

In each of these views, south is up as seen through an inverting telescope.

edge-on and disappear, the planet's magnitude drops to +0.9; but when the rings are wide open, Saturn can be as bright as magnitude -0.3. Why? The reason lies in the rings' composition: billions of tiny, icy particles, each in its own orbit around the planet. In fact, these particles may be entirely ice, not merely coated with it. In either case, the high reflectivity of ice makes Saturn's rings even brighter than the planet.

Even a 30mm (1.2 inch) refractor will show the rings of Saturn quite clearly; closer looks with larger apertures will reveal the rings' three major divisions, aptly named A, B, and C. With a 2.4 inch refractor, you can see a thin black line running through the rings, about 3/4 of the way toward the outer edge. This line is called Cassini's division (named after its discoverer), and is actually a gap separating portions of the ring from each other. Outside of this division is ring A — about as bright as Saturn's polar regions and 10,000 miles wide.

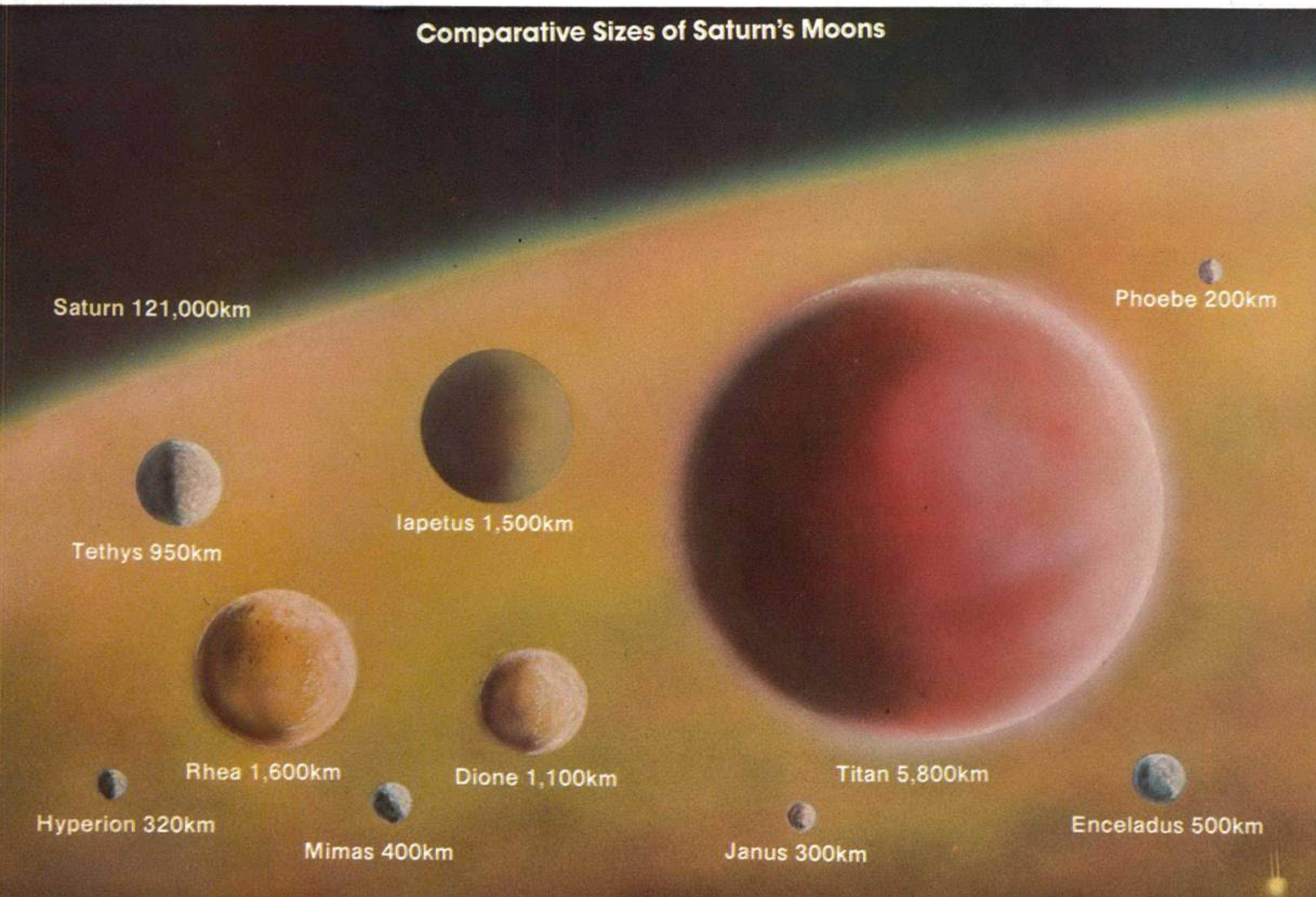
Ring B is wider (about 16,500 miles) and brighter than ring A. In fact, ring B is the brightest part of the entire Saturn system. Its brightness drops off slowly as it nears the planet. Inside ring B is ring C, more often called the Crepe ring. This ring, also about 10,000 miles wide, is much darker than either rings A or B. It can only be seen well through a telescope of *at least* eight inches aperture, as a dark shadow crossing the planet's surface — looking, in fact, much like a dark cloud belt.

Other gaps and divisions besides Cassini's in Saturn's rings have been reported from time to time; so far, the only one that has been definitely confirmed is Encke's division. This faint line is located about 3/5 of the way toward the outer edge of ring A, and you'll need at least 10 inches aperture to catch a glimpse of it.

The rings look quite substantial, but they're actually very thin. Estimates of their thickness range anywhere from 10 miles to a few feet. We get a dramatic demonstration of the rings' extreme thinness about every 15 years when, as we mentioned earlier, Earth passes through the plane of Saturn's equator. Because the rings rotate exactly in this plane, we see them edge-on; for a few months, the rings appear as a thin line stretching out on either side of Saturn's disk, and for a few days before and after the precise edge-on phase, they disappear entirely from view!

If Saturn were like Jupiter and had a similar,

The diagram below shows the relative sizes of Saturn's 10 moons, on a scale where 1/16 inch equals 100 kilometers (62.14 miles). Titan, the largest of the satellites, is the only one known to have an atmosphere — one that may approximate conditions on Earth several billion years ago. The smaller moons are probably ice covered, although Iapetus may be only partly so; its uneven reflectivity is as yet unexplained. Saturn appears in the background; on this scale, its diameter is about 75 inches. Artwork by Mark Paternostro.



Satellites of Saturn

Name	Magnitude	Diameter		Mean Distance from Saturn		Period of Revolution		
		miles	km	miles	km	days	hours	minutes
Janus	14	190*	300*	99,000	160,000	0	17	59
Mimas	12.1	250*	400*	116,000	187,000	0	22	37
Enceladus	11.8	310*	500*	148,000	238,000	1	08	53
Tethys	10.3	590*	950*	183,000	295,000	1	21	18
Dione	10.4	680	1100	235,000	378,000	2	17	41
Rhea	9.7	990	1600	327,000	526,000	4	12	25
Titan	8.4	3600	5800	759,000	1,221,000	15	22	41
Hyperion	14.2	200*	320*	920,000	1,481,000	21	06	38
Iapetus	11.0v	930	1500	2,213,000	3,561,000	79	07	56
Phoebe	16.5	120*	200*	8,053,000	12,960,000	550	11	*

*indicates value uncertain
v indicates variable

nearly vertical orientation, we'd never see the rings except as this thin line. But Saturn's axis is tilted from its orbit by about 26.7 degrees, and during its 29-1/2 year trip around the sun, Earth will pass through Saturn's equatorial plane twice. The last time this happened was in 1966; it will next occur in 1980. Between these years, Saturn's polar regions gradually come into view and the rings become more and more fully displayed. In 1973, the rings were wide open when Saturn's south pole was at its fullest tilt toward Earth. At present, the rings are closing as we head toward the edge-on phase; the northern regions of the planet will be displayed fully by 1987. Watch the rings carefully between now and 1980, and you'll see them slowly shrink from sight. Just before and after the edge-on phase, our view of the rings is extremely foreshortened; even Cassini's division disappears from sight.

Proof that Saturn's rings are made of billions of tiny particles and are not solid comes on those rare occasions when Saturn occults (passes directly in front of) a star. If the rings move in front of the star, it can be seen shining through them. Such an event will take place this year on Oct. 3, when Saturn and its rings will occult an eighth magnitude star called SAO 98871. The occultation will be visible from North America; as with all such planetary "cover-ups"; it should be an exciting event to watch.

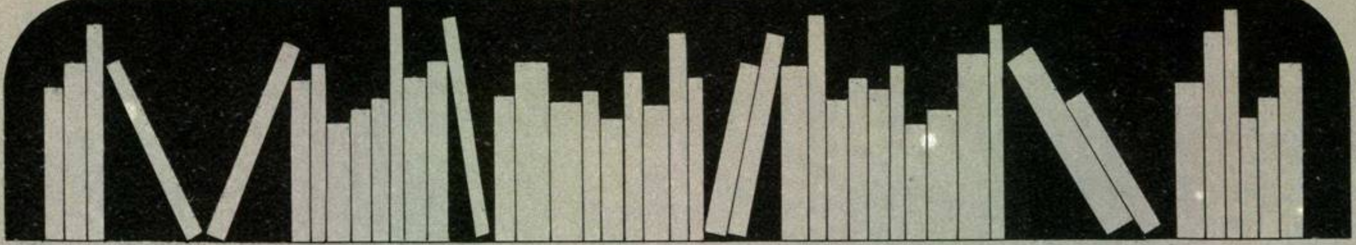
Just as the rings rotate exactly above Saturn's equator, so do most of the planet's satellites. Because Saturn has a large axial tilt, the moons can be seen"above" the planet when they swing behind it — except, of course, during the equatorial-view phase. The moons are fainter than those of Jupiter, but even so, the five brightest can be detected in a four inch telescope.

The largest and brightest of the moons, Titan, is visible in the smallest telescopes; its magnitude is about 8.4. Titan, in fact, is the largest moon in the entire solar system. (Some award this honor to Neptune's satellite Triton; don't confuse the two by their similar names.) You can pick up ninth magnitude Rhea in a three inch telescope, while a four inch will suffice for Tethys and Dione. The fifth bright satellite, Iapetus, varies greatly in magnitude. At western elongation (the point in its orbit where the moon lies farthest west of Saturn), Iapetus is even brighter than Rhea, but at eastern elongation, it's three magnitudes fainter and you'll need at least six inches of aperture. Like our own moon, Iapetus most likely keeps the same face to Saturn as it orbits the planet; one hemisphere, for some reason, is much more reflective than the other.

The other moons are more difficult objects. Mimas and Enceladus are so close to Saturn that, although both are about 12th magnitude, they're usually lost in the planet's glare; you may be able to pick up Enceladus in an eight inch telescope. Hyperion is also faint (13th magnitude), and you'll need a scope with six to eight inches aperture. Of the remaining two moons, Janus (the closest to Saturn) has only been detected photographically; Phoebe (the farthest from the planet) can be found if you search carefully.

Saturn's moons aren't as bright as the well-known Galilean satellites of Jupiter, but it's still fun to watch them orbit the planet. Tethys whirls around Saturn in less than two days, and Dione in less than three; Rhea takes 4-1/2 days, while Titan moves in a more sedate 15 day 22 hour orbit. Iapetus takes 79 days for a complete circuit of Saturn; its contrasting elongations are thus almost 40 days apart. For the appearance of Saturn's moon through the telescope, check the day-by-day chart on pages 44 and 45.

Saturn, with its magnificent rings, is an object of which no one can ever tire. To the beginning astronomy enthusiast and the veteran observer alike, the planet's chilling beauty provides both breathless excitement and deep satisfaction. At your next observing session, why not treat yourself to a look at Saturn?



Toward A Better Tomorrow With Aeronautical and Space Technology

200 pages, paperback, $1.55*

This is the "case for space". Apollo gave us more than goosebumps and nonstick frying pans, and since you are not liable to read much about the real benefits in the common news media (which has become bored with the whole subject), you might as well go directly to the original source. This new government booklet helps.

NASA officials James Fletcher and George Low give the official space agency sales pitch: weather satellites, Earth resources observers, air and water pollution monitoring, and space sciences. Numerous applications in medicine, fire fighting, rescue techniques, power generation and other everyday needs are listed and explained exhaustively, illustrating why most reporters became bored.

The brief discussion of large space telescopes and planetary exploration will be of interest to astronomy buffs, but celestial bodies have as yet a very limited representation in Congress (although within 1,000 years or so the human population off Earth may exceed the local census, as the population of the Americas today exceeds that of Europe). So the majority of this NASA presentation deals with technology and engineering. The "better tomorrow" advertised is a materialistic one — and is indeed authentic as far as it goes. If this is what you want to read about, the pamphlet is excellent if uninspiring. *James E. Oberg.*

**By U.S. Senate Committee on Aeronautical and Space Sciences; written at 8th grade level, it covers engineering and a little science. Stock number 5270-01959; for sale by Superintendent of Documents, Washington, D.C. 20402.*

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Lowell and Mars

by WILLIAM GRAVES HOYT

376 pages (illus.), hardcover, $13.95*
University of Arizona Press (1976)

The findings of the Mariner and Viking missions to Mars have been of incalculable value to astronomers and planetary scientists. Taken as a whole, they have also had an important effect on astronomy historians, for it has finally become possible to evaluate objectively the work of Percival Lowell, whose name is more closely associated with Mars than perhaps any other astronomer in history.

As most readers know, Lowell, taking his cue from the so-called *canali* discovered by Schiaparelli, hypothesized immense waterworks crisscrossing the surface of the planet, as well as the presence of the magnificent, dying civilization that supposedly built them. Lowell's ideas struck public fancy and touched off one of the greatest furors the science has known. Reactions to Lowell's theories, and the arguments that resulted, were pitched almost entirely on a high emotional level. The controversy might profitably be compared to that conducted today on UFOs; both believers and scoffers tend to be violently, emotionally pro or con.

Lowell's Martians had lost public favor by about 1910, but even in texts written 40 years later, his theories could not be discussed plainly, unadorned with the author's (adverse) reactions. It took the scientific missions of 1965 through the present to finally lay Lowell's ideas to rest, and allow them to be looked at with some objectivity.

Lowell and Mars is a major step in that direction. Without frills, Hoyt makes a perceptive study of the man and his ideas. As he states in his introduction: ". . . this book is not a biography in the ordinary sense of the term. Rather it is a study of a man's mind, a man's ideas. That these ideas were sometimes superficial and often erroneous is beside the point. Right or wrong, they were influential, a stimulant or perhaps a goad to other minds, and thus they belong to intellectual history."

It should not be supposed from this quotation that biographical information has been given short shrift. Hoyt's carefully documented research — much of it based on previously unavailable material from the Lowell Observatory archives — is extensive; this is probably as good a biography of Lowell as we are likely to get for some time. But the book's real contribution is in its study of the scientific method as it relates to the work of Percival Lowell. Chapter two, which contains much of Lowell's early biography, also has a superb discussion of the workings of Lowell's mind, his approaches to science, and his belief that "imagination" (or more precisely, the imaginative personality) was a prerequisite to scientific study. Lowell followed what Hoyt calls the uncomplicated approach: "He believed quite simply that scientific truths could best be reached by reasoning logically from facts." Conversely, Lowell thought that "negative evidence was worse than no evidence at all" — a belief in striking contradiction to true scientific method, where negative evidence is sometimes the strongest and most valuable kind.

Lowell's Mars, of course, fills the major portion of the book, and Hoyt's discussions of Lowell's books and ideas are as they should be — remarkably cool and objective, with none of the emotional heat that has so often been the tone of previous writing on the subject. Hoyt makes Lowell's books seem so interesting that the temptation to find and read these volumes is irresistible.

Finally, a major contribution of **Lowell and Mars** is a thorough and complete account of Lowell's positive contributions to astronomy — contributions that have been unfairly neglected until now. As Hoyt states, the rebirth of solar system study and planetary science is a direct outgrowth of Lowell's Mars work. Advances in photography can be traced to Lowell's and others' attempts to prove (or disprove) the existence of the canals. And Lowell's insistence on the most perfect atmospheric conditions possible for his observatory site was the first attempt to obtain an excellent location for serious astronomical work.

Hoyt's writing style — simple, clear and direct — is a joy to read. The book is well illustrated with a selection of Lowell's drawings, photographs and maps. In short, this is the best book yet on its subject, and is highly and enthusiastically recommended by the editors of ASTRONOMY. *Henry J. Phillips.*

**Also available in paperback for $8.50.*

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Apollo Expeditions to the Moon

edited by EDGAR M. CORTRIGHT

314 pages, hardcover, $8.90*
NASA (1975)

The Apollo Spacecraft: A Chronology

edited by COURTNEY G. BROOKS and IVAN D. ERTEL

286 pages, paperback, $5.20**
NASA (1976)

No one who remembers that Sunday afternoon many summers ago when men first reached the surface of the moon can really appreciate how the event has been "historified" until they see the Apollo project locked in history books as a past event. To most researchers today, manned flight to the moon is a closed chapter in the history of space exploration.

These two publications represent opposite trends in the history of the Apollo program. The first is a beautifully illustrated collection of personal memoirs of the men intimately involved with the project. The second is a loosely edited collection of obscure memos generated by those men.

Expeditions is probably NASA's best attempt at portraying the real inside story of Apollo from the preparations to the Kennedy commitment, the tragic 1967 fire, through the first moon orbital flight and the first landing. The closing chapter offers a view of the future, but the book is first and foremost a portrait of a glorious past.

Expeditions belongs in every space library. A list of authors would read like a list of the men who make Apollo a reality: Webb, Von Braun, Petrone, Kraft, Phillips, and a number of astronauts. Many of these men worked behind the scenes, and this is the first popularized history to give them the credit they deserve. Most of them have since left the space program.

Chapter by chapter, a reader sees the rationale for a moon program and for the ultimate course chosen: the lunar orbit rendezvous. Unknown to most space enthusiasts today, this was one of three major techniques which were considered. The decision had to be made on a combination of quantified guesses and outright intuition. It is characteristic of these men that their guess was correct.

A guess that was not correct was the basis for the greatest space tragedy of the 1960s. Actually, a combination of factors which all went wrong together caused the deaths of the first Apollo crewmen in the pad fire early in 1967. On the other hand, observers at that time were beginning to feel that the project was out of control and that some major reworking was going to be needed. Since other systems like the Lunar Module and the Saturn 5 second stage were also lagging, the Apollo fire probably did not delay the ultimate moon landing.

The last leg of the "moon race" began in 1968. Both the Soviet Union and the United States were neck and neck in their plans to send men around the moon. (A Soviet moon landing program was several years behind Apollo, but they counted on a major Apollo delay into the early 1970s to enable them to catch up and make the first manned touchdown.) A study group in Houston recommended that Apollo 8 be sent around the moon, and NASA officials took steps to see that these accelerated plans did not fall into the hands of the Russians.

And, of course, the rest is history. Later moon missions, described by astronauts Collins, Aldrin, Conrad, Shepard, Lovell and Schmitt, accomplished the primary goals of Apollo, on schedule, under budget, and in the glare of publicity.

In contrast, the **Chronology** is the raw material of history, although it is hard to imagine who will need it. Covering the period from October 1964 through January 1966, this volume is part of a series being put out by the NASA historical office. One is tempted to view it as a make-work project, although a persistent reader can obtain unique insights if he tries hard enough.

Do we need a "quick-donning" spacesuit, and how would it be useful in a real emergency? What do we do to design around a disabled astronaut in the Command Module during lunar orbit rendezvous? Should the Lunar Module have fuel cells or batteries? What kinds of lunar sample handling facilities are needed? Would it pay to send a Gemini around the moon (as was considered in 1965)?

What is shown here is the repetitious loop of problem solving which succeeded with Apollo. A problem leads to fixes which cause more weight in the spacecraft, which results in the removal of equipment or capabilities, with the subsequent redesign. This causes further problems and the loop starts over again. It's not endless, since hopefully the design will converge on the proper one.

This volume does not include the Apollo fire, and there are no hints of any problems in that area (neither "fire" nor "flammability" are listed in the index). A list of major technical problems from a meeting on Sept. 10, 1965, does not mention any concern for fire in the spacecraft.

The history of Apollo is a dynamic process, now that Apollo is history. These two books are very different aspects of that study. The first is easy to read, and the second is easy to put down. Each will appeal to a unique audience. *James E. Oberg.*

**Stock number SP-350. **Stock number 033-000-00614-4. Both available from the Superintendent of Documents, Washington, D.C. 20402.*

North Star to Southern Cross

by WILL KYSELKA and RAY LANTERMANN

152 pages, hardcover, $8.95*
University of Hawaii Press (1976)

Primarily a field guide to the heavens, **North Star to Southern Cross** is intended for a broad range of readers — mostly those spurred deeper into astronomy by looking at the sky. For the most part, Kyselka and Lantermann have succeeded in this aim; much can be learned from this presentation of stars in the southern sky.

The book starts off with a historical perspective and, considering the limited space for development, does a better job than most astronomy textbooks — although errors do occur. On page 6, the diagram of the Ptolemaic system is not quite right. The epicycles of Mercury and Venus are not in line with the sun and do not have the proper size ratio. And, the radii of the epicycles for Mars, Saturn and Jupiter are not parallel to the Earth-sun line.

The authors then move to the zodiac and other constellations. The month-by-month guides to the sky are well-written and informative.

The last part of the book is the weakest, as it attempts to cover too much too fast. The section on stellar evolution includes occasional undefined technical terms. Before dealing with cosmology, the authors present a good variety of ancient creation myths, but the jump into cosmology comes too quickly, and again concepts (such as the open universe, closed universe, and space-time curvature) speed by much too fast for the average reader to understand.

A few minor errors do crop up, but they don't really detract from the book. No credit is given to Milton Humason for his part in discovering the redshifts of galaxies. Shapley and Curtis did not debate the position of the sun in the galaxy, but they did clash on the size of the galaxy and whether or not spiral nebulae were other galaxies. While the Hubble constant is mentioned, the concept is never explained.

In general, this is a good book for the astronomy enthusiast interested in the southern sky. *Michael Zeilik.*

**Also available in paperback for $3.95.*

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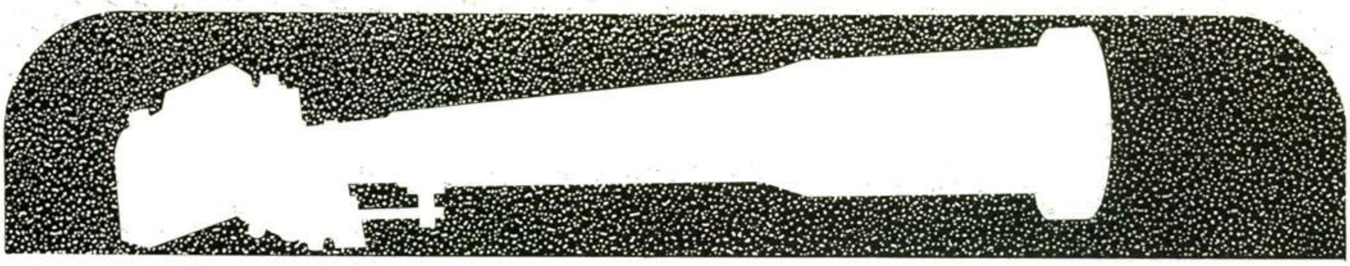


PHOTOGRAPHY IN ASTRONOMY

Cold Cameras: Part 1

by
Richard Berry

Many astrophotographers who live in the colder parts of the world have noticed — by accident — an interesting effect: An exposure sufficient to record a certain object in the wintertime simply won't work in the summer. Or they may have found that a 15 minute exposure gave a good result on the bright starclouds of the summer Milky Way — but then the same exposure on the winter sky turned out to be overexposed!

When film is exposed at normal room temperatures, the latent image formed in the film by light is reasonably stable. But before the latent image is fully exposed, it becomes unstable and decays in a matter of minutes. During ordinary exposures that last only a fraction of a second, a latent image will be completely formed before any significant decay can take place — but astronomical exposures last a very long time, and the latent image decays as it is being built up in the film. The result is that most films designed for ordinary photography are unsuitable for astrophotography when exposures run into many minutes. The image literally decays almost as fast as the incoming light builds it up.

However, by refrigerating film to a temperature around -40 degrees Fahrenheit (-40 degrees Centigrade), the decay of the partially formed latent image is inhibited. In cooled films, long exposure "adds up"; all the light that falls on the film will contribute to the final image.

During the first half of the 20th century, various film manufacturers invented sophisticated astronomical emulsions that eliminated the effects of latent image decay. Most astronomers and astrophotographers simply used the superb special purpose films and avoided ordinary snapshot films for their deep sky pictures. Besides, with black and white films there was no real problem: Everybody just assumed that exposures had to be hours and hours long.

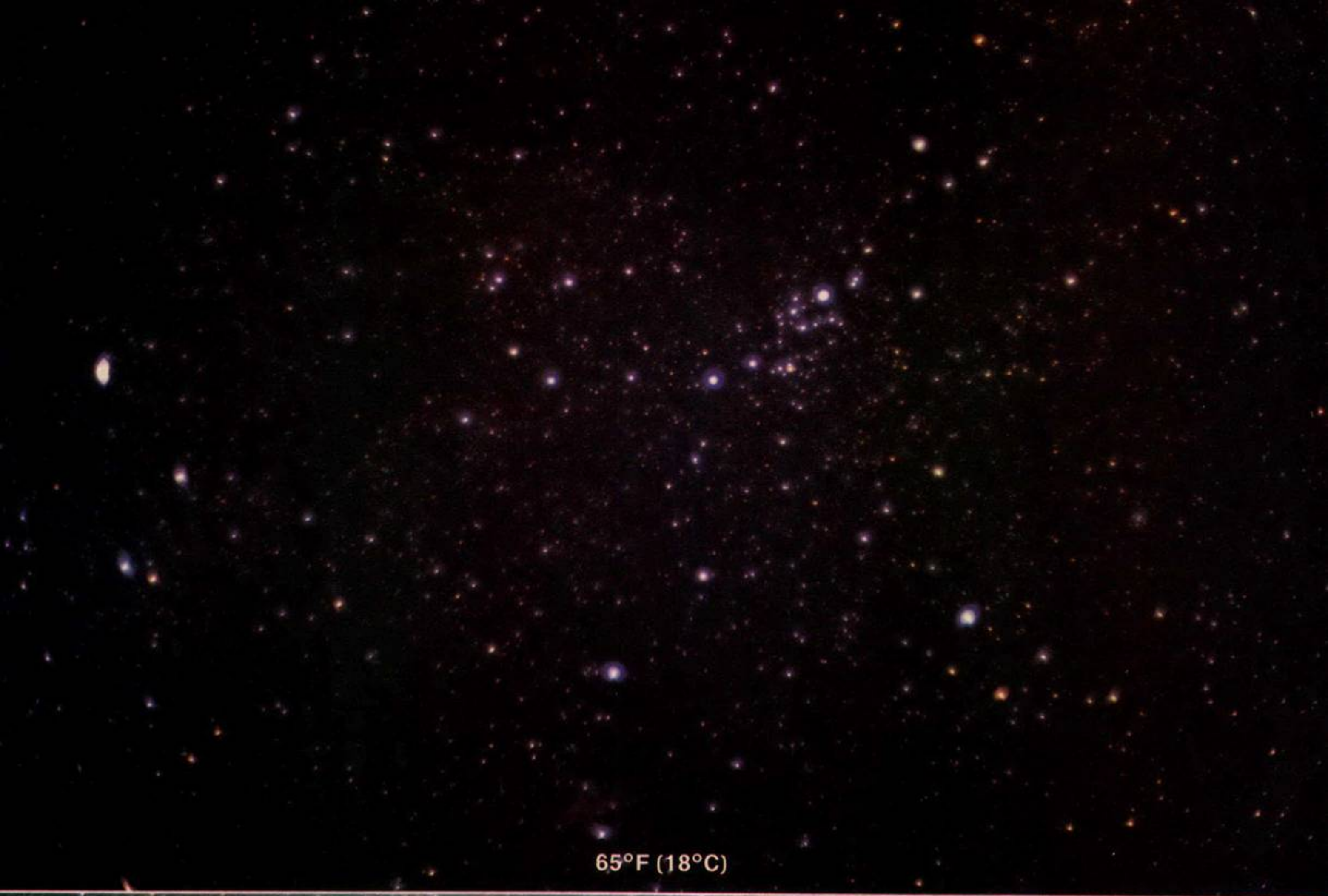
But the invention and increasing popularity of color film changed everything. Color film is affected more than black and white films, for the latent image decay effect (called *reciprocity failure*) is far worse in color film than in black and white. Any reciprocity difference between the three emulsion layers of color films shows up in a hideous color change.

Something had to be done!

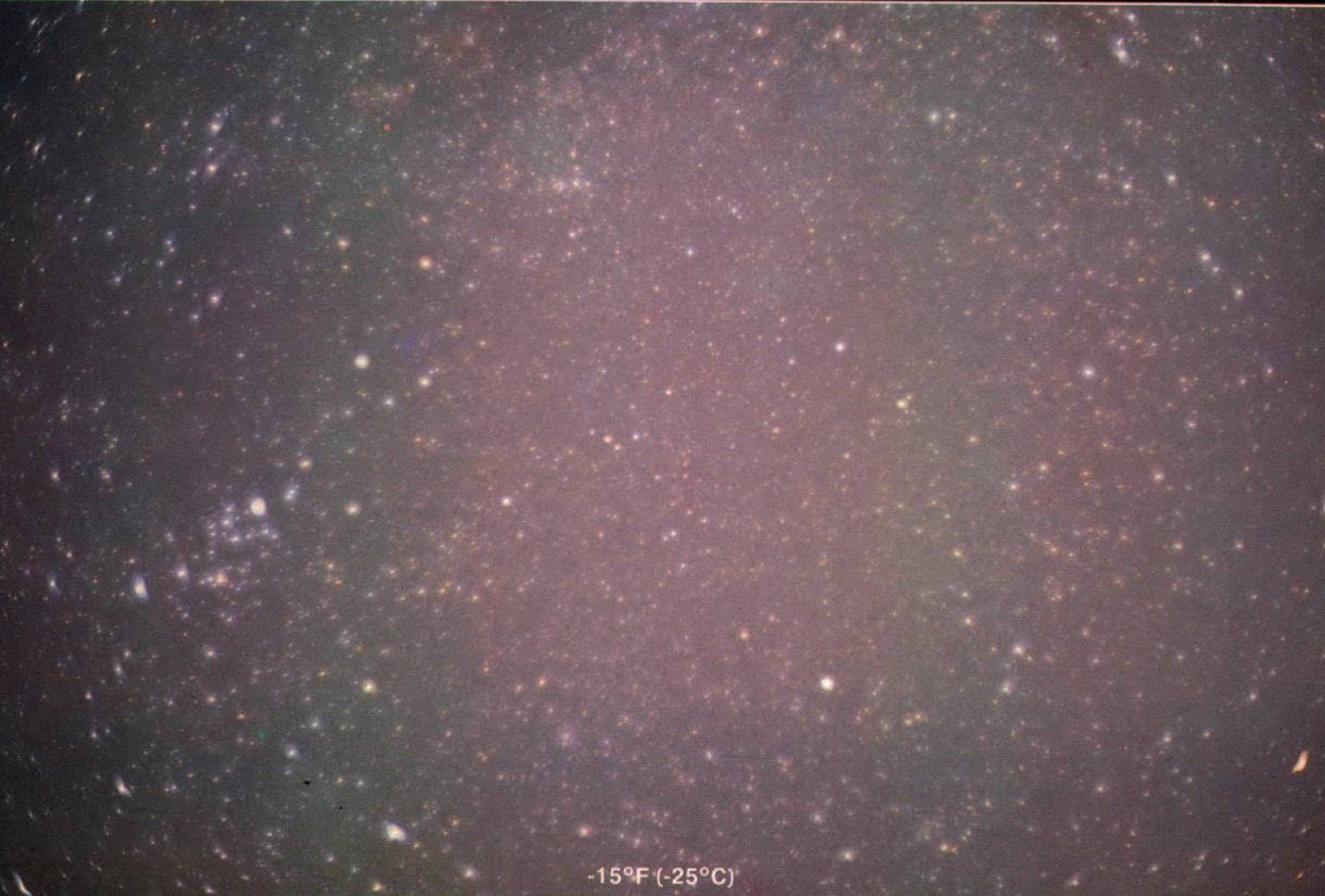
As a result, the film chilling process was "dug up", dusted off and widely publicized. Devices known as "cold cameras" were invented. The purpose of a cold camera is to chill film to the point where reciprocity failure is greatly reduced. Then color films — as well as some of the faster, fine grained commercial black and white films (which can provide color drama or black and white quality unmatched by grainy, special purpose films) — can be used at the telescope for high quality, deep sky photographs.

Cold cameras aren't for the beginner. Tricky

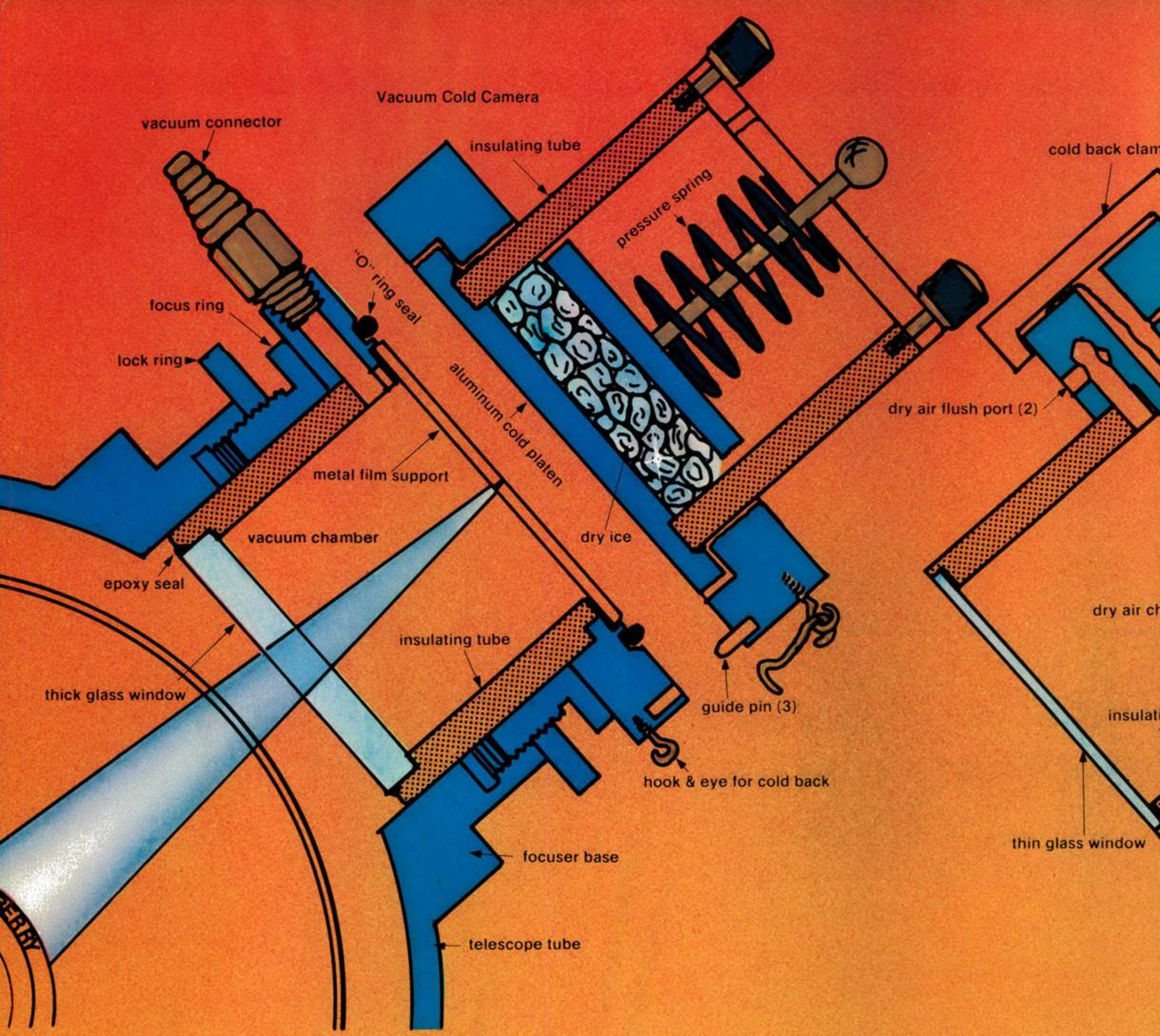
Two similar exposures of Perseus show the drastic effect of temperature on the recording ability of color film. The upper photograph was taken on a warm night during Indian summer weather; the lower one was taken on a cold winter night in Canada — one of the coldest nights that winter! Both photos, using the same camera and High Speed Ektachrome film, are 15 minute exposures at f/1.4; each was taken on a very clear night. Photographs by Bill Morrow.



65°F (18°C)



-15°F (-25°C)

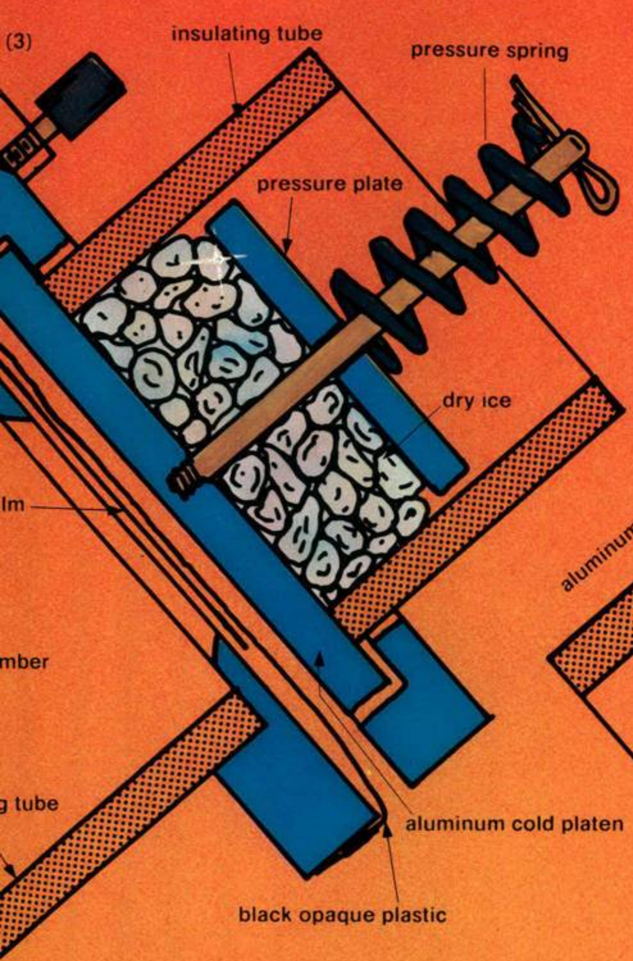

Vacuum Cold Camera
vacuum connector
insulating tube
cold back clam
pressure spring
"O" ring seal
focus ring
lock ring
aluminum cold platen
dry air flush port (2)
metal film support
vacuum chamber
dry ice
epoxy seal
dry air ch
insulating tube
thick glass window
guide pin (3)
insulati
hook & eye for cold back
thin glass window
focuser base
telescope tube
ERRY

Illustrated here are three different cold cameras designed for small telescopes, emphasizing simple construction, easy operation, and close attachment to the telescope. At left, a vacuum cold camera is attached to a telescope; in the middle, we see a dry air design; and at right, a solid plug design — the simplest kind to build. If you build a cold camera, you'll have the satisfaction of your own custom design. Artwork by Richard Berry and Mark Paternostro.

to operate, "fussy" to load and unload, they require special equipment and materials hardly suited for beginners. But in the hands of an astrophotographer who has already mastered the basics, they provide the ultimate in high quality color and fine grained black and white astrophotography.

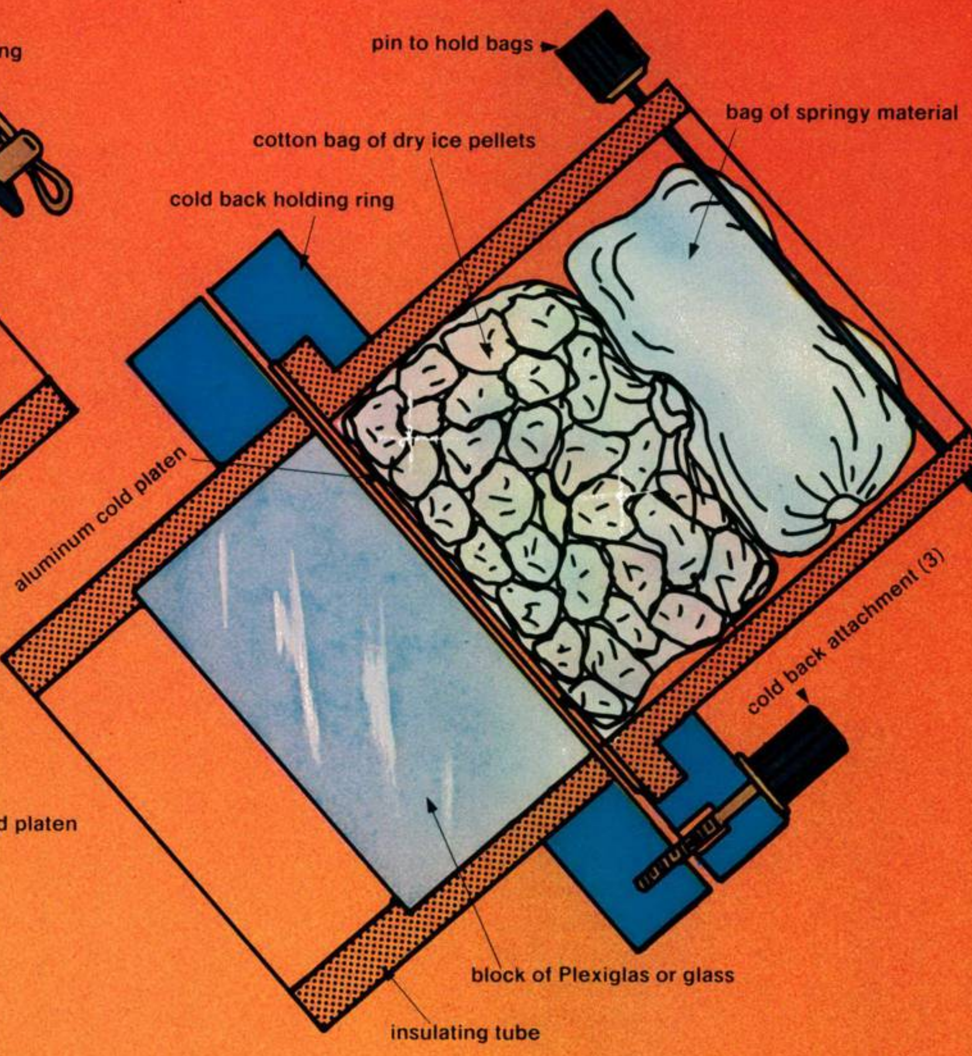
Films in the 103a- series are superior in many respects to cooled black and white emulsions. Spectroscopic films provide better choice of color sensitivity, give higher contrast, and are much easier to use than a cold camera. Cooled black and white films, however, usually are less grainy than the 103a- series. There is no easy alternative to cooling color film if you want first class color, high speed and short exposure, because cooling eliminates reciprocity failure without other adverse effects.

Why do cold cameras have to be so special? Why can't you just press ice cubes or dry ice against the camera back to make it cold and then just snap away normally — but with the advantages of cooling built in? The major problem is water condensation and frost from the atmosphere. Film — or any object for that matter — cooled to -40 degrees Fahrenheit (-40 degrees Centigrade) in air is quickly covered with a layer of ice crystals. Water vapor is so common in Earth's atmosphere that not even the driest deserts or the highest mountains are free of frost. Obviously, frost prohibits light from reaching the film. Then, when the film is



Dry Air Cold Camera

(3)
insulating tube
pressure spring
pressure plate
dry ice
lm
mber
g tube
aluminum cold platen
black opaque plastic



Solid Plug Cold Camera

pin to hold bags
bag of springy material
cotton bag of dry ice pellets
cold back holding ring
aluminum cold platen
cold back attachment (3)
block of Plexiglas or glass
insulating tube

warmed again, the frost melts making the film wet, and wet film is very sticky and easily damaged. Also, you'll find that blotchy marks often appear on the image due to condensation when cold film is removed from a cold camera and exposed to moist air.

Cold film also becomes brittle. In cold weather, sprocket holes in 35mm film often break; if bent, cold film can crack down the middle. If you simply wind the film, it might snap. Finally, extreme cold causes all sorts of delicate mechanisms to malfunction — cameras included. A cold camera must be built without moving parts that can jam or stick, and that can tolerate repeated wetting — and most 35mm cameras cannot. In addition, you have to be able to focus your cold camera while it is on a telescope, and putting the film in and taking it out wouldn't be so complicated that it can't be done in the complete dark. You must also remember that *severe frostbite can result from handling dry ice and other coolants*. The design has to be safe.

Such requirements are formidable!

How Cold Cameras Work

The obvious solution used by several early cold camera astrophotographers was to pump the air out in front of the film. (Certainly no frost would occur if there was no air.) Light could still reach the film through a glass window at the front of the vacuum chamber. Cooling was usually accomplished with dry ice held in a metal chamber behind the film. Dry ice maintains a temperature of -109 degrees Fahrenheit (-78 degrees Centigrade), but inevitable heat leaks never let the film actually reach this temperature; the film is normally cooled to -40 degrees to -60 degrees Centigrade — the very best range of temperatures. Since a vacuum is a good heat insulator, the window took a long time to become cold enough to accumulate dew or frost. Of course, a vacuum pump was necessary, and some skill was required to build the parts for the airtight chamber. Special interchangeable holders (each carrying one piece of film) made changing films quick and easy. The finest results using cold cameras have undoubtedly been obtained with home built vacuum cold cameras, but the complexity of these cameras has limited their use.

Because dry ice evaparates in a few days, it is difficult to store — so it isn't the best way to cool the film. Probably the best method currently available is using the cooling effect that liquid carbon dioxide gives when it's expanded through a tiny hole. As it expands, it makes instant dry ice snow. In its cylinder, liquid carbon dioxide lasts indefinitely, but delivers instant cold with the turn of a valve. Liquid carbon dioxide systems cost a few hundred dollars, so you may find dry ice the most economical coolant. Other coolants such as liquid nitrogen are not good because they are *too* cold: Cooling to the liquid nitrogen temperature causes your film to lose speed.

Literally hundreds of schemes must have been tried to avoid the bulk and difficulty of vacuum pumps and airtight seals. Ways to make very dry air — air so dry that no water would condense on the film — were sometimes successful. But most designs failed; cold air cooled the window and the window dewed over. Some cold camera designs that worked well in the dry American southwest didn't work in the humid east. Dry air cold camera designs are probably the simplest to build at home, and they can work very well especially in already dry climates.

Finally, a workable scheme was devised by a high school student in New Jersey. Instead of vacuum or gas, he used a solid transparent slab of plastic and pressed the film directly against it. The film was cooled from the back by a metal box of dry ice. Although the film was exposed to air, the air layer was so thin (well under 1/1000 inch) that no appreciable amount of water could condense on the film. Commercial versions of this design are now available.

Other cold camera designs exist, of course, but they are usually variations on one of the basic types: the vacuum chamber type, the dry air type, or the solid plug type. Within each different design, every astrophotographer who has built one has taken a somewhat different route. That's part of the fun of astrophotography. Building a cold camera can be a wonderful project if you love to tinker around building things. You can buy a commercial unit, but there is a lot of satisfaction in designing your own and then building it from whatever tools you and your friends have available.

Attaching a Cold Camera to Your Telescope

It's silly to try to funnel the light from your telescope down the narrow pipe of the eyepiece tube before bringing it to a focus. If you want to use the whole image your telescope can provide, you should install a very short focuser with a large diameter drawtube; then you'll get all the image your telescope can deliver. In addition, you'll find that the closer the film is to the side of the telescope tube, the smaller the diagonal needed to transfer all the light from the main mirror to the film. If you own one of the unmodifiable commercial Schmidt-Cassegrains, the field will be limited by the telescope optics, and there isn't much you can do about it. But if you have a home built Newtonian and are willing to make a few changes to accommodate a cold camera, you're on your way to owning a first-rate photographic telescope.

Since everybody has different equipment and needs, there can be no single set of directions that are best for modifying any particular telescope. But the illustrations on page 52 show how a cold camera and telescope can be joined in a simple and effective mounting.

Starting Out in Cold Camera Astrophotography

You're interested in deep sky photography but the exposures are too long. You've tried the spectroscopic emulsions and they work wonders, but they're black and white. You want color. What does it take to get started in cold camera astrophotography — a method that promises fantastic color results?

To be perfectly blunt, you must first be a pretty good astrophotographer. You have to have a telescope that you can accurately focus and guide. You should be able to develop your own films or have found a film processing lab that will do odd bits and pieces of film processing for you. With these prerequisites, you'll gain something from a cold camera. But a fuzzy, blurred, badly guided cold camera photograph is no better than any other fuzzy, blurred, or badly guided photograph.

Second, you'll have to build or buy a good cold camera. You can build a cold camera with ordinary home workshop tools and materials available in good hardware stores and hobby shops. But even if you buy a commercially made cold camera, you'll find some modifications will be necessary before you can begin serious work.

Lastly, you'll need access to a good dark sky. Cold cameras can get you down to the limit in perfectly dark country skies. There isn't too much point in shooting rabbits with an elephant gun — nor is there any need to use a cold camera in a badly polluted sky. If you don't live out in the country, you should be prepared to take astrophotography camping trips. ◆

Editor's Note: Next month in " Cold Cameras: Part 2", we'll tell you how to go about freezing your film without freezing your fingers, and how to set up and use home built and commercial cold cameras.

ASTRO-NEWS

Latest News From the World of Astronomy

NASA Develops Mobile Lander For Unmanned Planetary Use

A new vehicle mobility concept, developed by NASA's Marshall Space Flight Center, holds promise of extending unmanned explorations on the surface of Mars and other planets. Known as the Elastic Loop Mobility System (ELMS), the concept is an outgrowth of work done at Marshall and elsewhere on the successful Lunar Roving Vehicle (LRV). Carrying astronauts and equipment, the LRV extended exploration of the moon far from the Lunar Module's landing site.

NASA has landed two Viking spacecraft on Mars, and each has transmitted to Earth large amounts of data about the atmosphere and surface of Mars. But the Viking landers are limited in their exploration, since the spacecraft are immobile on the Martian surface. According to scientists, what Viking needs now is mobility. ELMS or other similar systems could provide this roving ability for a Martian lander.

ELMS involves a continuous, elastic loop track device which could be used in place of each of the three landing pads on present landers. It would distribute the vehicle weight uniformly over a relatively large area, and combine the suspension and drive systems of the spacecraft into one compact, lightweight package.

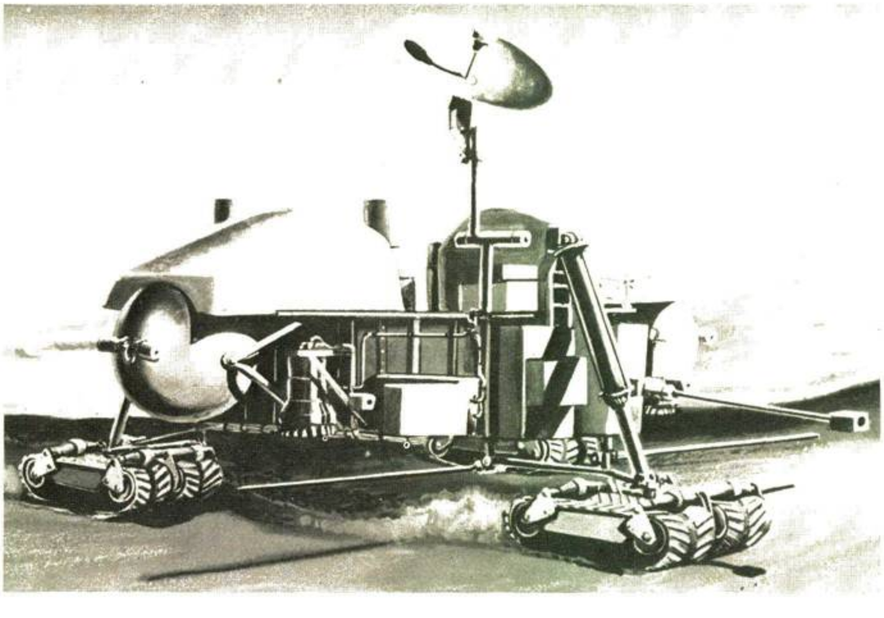
The ELMS' main structural component, the continuous elastic loop, is barrel shaped. The geometry of the loop and its nonlinear spring characteristics enable the system to apply uniform and low contact pressures on the ground, and to provide its own suspension system, yielding excellent mobility on soft soil surfaces and a smooth ride over hard and rough terrain. These features, combined with the low internal energy losses in the ELMS traction drive system, result in high mobility performance, low energy requirements and high power efficiency. Mobility performance tests on large scale ELMS and ELMS models have shown that the slope climbing capability of this system on compact, fine grained granular soils (such as those on the Martian surface) enables it to negotiate slopes of 30 to 40 degrees and, on hard surface, as steep as 45 degrees. The same tests have shown that ELMS vehicles can surmount rigid-step obstacles with a height up to 85 percent of ELMS' length, and can cross crevasses with a width up to 90 percent of ELMS' length. In addition, ELMS vehicles exhibit high stability when the vehicle is stationary, and high maneuverability on both soft soil surfaces and hard, rough terrain.

A recent study conducted by experts involved with the project concluded that integration of the ELMS with present Viking lander hardware is technically feasible. Such a concept would provide a mobile laboratory, capable of conducting unmanned scientific missions on the Martian surface for a period of six months, along traverses ranging up to 90 miles (150 kilometers). According to scientists, such a capability would open a new era in planetary surface exploration. The study also indicated that the ELMS could carry an expanded chemistry and biology package, which would include chemicals for soil analysis and a mass spectrometer to probe soil content.

More recent reviews of a potential mobile Viking mission to Mars, using the ELMS concept, are considering missions that can be extended to two years, along exploration routes ranging up to 300 miles (500km).

The same study has shown that ELMS is currently the most advanced design for a Viking mobile lander. Be-

ELMS *continued on page 56*



This illustration depicts a modified Viking lander in which the landing pads were replaced by a device called the Elastic Loop Mobility System. Viking officials have estimated that if funding were available, the system could be launched in 1979 at a cost of $300 million — compared to the Viking lander's cost of $1 billion. NASA photograph.

Spectral Lines Indicate Unidentified Molecules

Recent advances in the field of radio astronomy have led to an increase in the number of unidentified spectral lines. This is due to the increased sensitivity of the equipment being used.

The 40 or so molecules known to exist between the stars in the Milky Way generate about 250 distinct radio signatures or spectral lines. Many of these 40 molecules have isotopic variations (being identical in all directions) — as in the case of carbon monoxide (CO), which is made up of carbon 12 plus an oxygen 16 atom. The carbon count varies. Radio signals from carbon monoxide consisting of carbon 13 instead of carbon 12, as well as a variety that contains oxygen 18, have also been detected.

Many of the 40 molecules have corresponding isotopic species in space, which gives rise to the large number of spectral lines found so far. In addition to the 250 unidentified signatures, there are many radio signals coming from molecules that have not yet been identified. To date, the list of unidentified radio signatures includes some 50 wavelengths at which a signal is found, but for which no one can give a definite indication as to the responsible molecule. Conservative estimates claim that, allowing about three signature lines for any given molecule, the list may require the further identification of at least 17 more molecules in space.

In addition, scientists are continually making new laboratory measurements in an attempt to decipher radio wavelengths. It becomes a matter of taking the data to a radio telescope, tuning the receivers to the correct wavelength, and pointing it at the most interesting gas and dust clouds in the Milky Way. If the expected signals are picked up, it is very likely that a new molecule may be detected. Since all molecules generate many spectral lines, positive identification depends on finding three or four of the characteristic signatures for the new molecule.

The latest case of such a lab measurement leading to a new search in space concerns the simplest amino acid known as glycine. Recently, Australian researchers have measured its properties in the laboratory and have begun a radio astronomical search for this basic life molecule.

Astrochemists and radio astronomers believe that as receivers increase further in sensitivity, radio wavelengths around a few millimeters to a few centimeters will begin to look like a picket fence with new spectral lines popping up all over the place. Unfortunately, laboratory measurements are not keeping up with the discovery rate of the new lines, primarily because the lab experiments are very difficult to perform. At the same time, the theories explaining the existence of the molecules in space are also well behind the discovery list. The formation of only the simplest molecules has been accounted for, while the heaviest ones are still an enigma. The underlying fact that is common to the list of known molecules is that carbon based, organic molecules are everywhere in space, and indicate that the chemistry we find here on Earth is also common throughout the Milky Way galaxy.

Space Industrialization Possible

Scientists at the Marshall Space Flight Center have strengthened the argument that materials can be manufactured better in space than on Earth. They reached their conclusion from careful studies of the information and photographs taken from the "Dendrite Remelting" experiment on the Space Processing Applications Rocket-1 (SPAR-1).

The concept of manufacturing materials in space has long fascinated scientists and science fiction writers alike. Scientists have feared that the absence of gravity would be outweighed by the creation of other problems which would make it economically impractical to attempt space manufacturing.

The point in contention was whether or not there was fluid motion in the absence of gravity.

The scientists, Carolyn Griner and Dr. Mary Johnston of the Marshall Center, believed that gravity was the greatest cause of fluid flow, and that without it, the material involved would disperse in a uniform matter. Other scientists disagreed, saying that factors such as surface tension and shrinkage of a liquid-turned-solid might be the major factor in fluid flow.

The test material (four cubic centimeters of ammonium chloride) was deposited with some water into a very small, transparent vial that had temperature monitoring devices attached to it. The vial was mounted near a 35mm camera that was fitted with large size film.

The sample was kept in a liquid state above 72 degrees Fahrenheit (22 degrees Centigrade) until the rocket reached the weightless stage. At that point the thermal devices were activated, thereby reducing the temperature and solidifying the liquid. The entire process was recorded on film, making it the first time scientists have been able to watch the process take place under weightless conditions. "Heretofore, it had been after-the-fact observation," Johnston said. "What happened to it during crystallization was a matter of speculation and theorizing.

As the sample on SPAR-1 cooled, it formed dendrites (resultant growths of the crystallized material). The dendrites did not move, break or settle which resulted in uniform freezing as the liquid turned to a solid. The dendrites that formed in the Earth based version of the experiment broke off, moved around, and settled to the bottom of the vial disturbing the uniformity of the solid.

A practical application of this sort would be the manufacturing of ball bearings, which would last longer because they would be homogeneous throughout. Manufacturers on Earth have attempted to produce a perfectly balanced ball bearing, but have been unable to do so because of gravitational effects.

According to Griner, the goal is to be able to control the crystalline structure of materials. "Control would enable us to make a material uniformly strong, stronger at one end than the other, stronger in one direction — or any way we wish, to meet a specific need."

ELMS *continued from page 55*

cause of the low ground clearance of the Viking lander spacecraft, and low ground pressure tolerances on soft Martian soil, wheels cannot be used. Conventional "crawler" tracks were also ruled out because of weight, design complexity, high energy consumption and low reliability, when considered for spacecraft use.

The organizations involved with the project in addition to the Marshall Space Flight Center include: Lockheed Missiles and Space Co., the U.S. Army Corps of Engineers, Langley's Viking Project Office, and the Martin Marietta Corporation.

Anglo-Australian Telescope

While the November 1976 meeting of the Royal Astronomical Society in London focused primarily on geophysical interest, RAS member Dr. M.V. Penston reported on the progress now being made with the 3.9 meter (4.2 yards) Anglo-Australian Telescope (AAT) and other instruments at Siding Spring in Australia. He included information on studies of faint galaxies (previously thought to be ellipticals but now shown as having faint spiral arms), and the quasar which currently holds the title "most distant object known in the universe".

Several large telescopes are operating in the southern hemisphere, where optical astronomers are likened to "kids in a candy shop" with the many opportunities to study in detail objects which have seldom been photographed before. The kind of "candy" favored at the AAT site combines close cooperation with radio astronomers to pin down the nature of radio sources, studies of very faint galaxies made possible through improved photographic techniques including the use of the highly successful IIIaJ emulsion, and strong interest in emission line objects.

The latter interest marks a shift of attention solely due to new observing techniques. When photographic spectra were the sole source of information about distant objects, absorption lines were widely studied simply because they show up as prominent dark features against a bright background. At the AAT and other new telescopes, however, direct spectral traces are built up before the observers' eyes on television screens as photons arrive at the business end of the telescope, and are counted electronically. With this technique, it is the emission lines that build up as peaks on the plot, futher encouraging study of their nature and origin.

In terms of sophisticated electronics for pulling the maximum information from the minimum number of photons, the AAT is supposedly in the same league as the 120 inch telescope at Lick Observatory (where the observing team has long been regarded as unofficial champions in this field). The automatic computer control at AAT gives a pointing accuracy of better than 2.5 seconds of arc.

Penston stressed that the comfort and ease of operation of a modern instrument such as the AAT is a prime factor in ensuring that good use is made of available time, making it easier for observer and operator to make the right decisions at the right time.

But not all the new advances depend on electronics. The improvement in photography made possible by the new emulsion has shown very faint features around several galaxies, including NGC-3256 which Penston described as having "huge, tenuous spiral arms". Also, several "ellipticals" are now shown to have very faint but clearly present spiral arms around the central bright galaxy. Explanations for these phenomena are not yet available.

Like all good showmen, Penston saved his bombshell for the end — the recent identification of Parkes radio source 2142-75, with a quasar shown by AAT measurements to have an absorption redshift of 3.56, and emission at a redshift of 3.93. If correct, this makes the object the most distant known in the universe, assuming the standard cosmological interpretation of redshifts. However, with improved improved photography bringing out ever fainter images, and improved electronics yielding even better spectral identifications, there is reason to expect the record to be broken soon. Perhaps the AAT team's special combination of interests will soon produce identification of a quasar with a redshift beyond four.

Soviets Search For Neutrinos

Dr. A. B. Severniy, the director of Russia's famous Crimean Astrophysical Observatory, has announced plans for the construction of several detectors for solar neutrinos in the northern Caucasus mountains. The detectors will use gallium and lithium.

The failure of recent American attempts to detect expected neutrino flux from the solar interior has led to a number of fundamental questions about nuclear and stellar physics. If the sun behaved as scientists expected, neutrinos should have been detected.

Dr. G. T. Zatsepin, corresponding member of the Soviet Academy of Sciences and director of the neutrino search, believes it is still too early to revise scientific notions about processes in stellar interiors. It will first be necessary to capture a neutrino of low energy, Zatsepin reported.

BRIEFS

● A new laboratory, the Manipulator Development Facility, at NASA's Johnson Space Center is currently determining how to apply the use of industrial robot and teleoperator technology to the movements of delicate instruments and cargo in and out of the space shuttle orbiter.

● Experiment results from radio transmitters placed on the moon as long ago as 1969 are still being received at the NASA laboratories in Pasadena, Calif. and Greenbelt, Md. Five nuclear transmitters are relaying information from the following: two experiments left by the Apollo 12 mission (November 1969); three from Apollo 15 (July-August 1971); three from Apollo 16 (April 1972) and five from Apollo 17 (December 1972), for a total of 13 experiments.

● Physicians at NASA's Johnson Space Center are gathering data on female physiological performance and tolerance limits as an aid in setting criteria for recruiting the first female astronauts.

JSC cardiologist Dr. R. L. Johnson is seeking answers to whether women respond differently than men of comparable age to treadmill exercise and to circulatory system stresses induced by decreased lower body pressure. Women employees at JSC are being asked to volunteer for testing on a treadmill and in a Lower Body Negative Pressure device to provide baseline data.

● A solar powered refrigerator is being used to store vital medications for the Papago Indians living in Sil Nakya, Ariz. The refrigerator is part of a program sponsored by the Energy Research and Development Administration.

The villagers previously had to travel 32 miles to a nearby hospital for medications. The refrigerator will reduce the cost and hardship of obtaining these drugs, in addition to storing perishable foods to be kept on hand to improve villagers' diets.

● The first High Energy Astronomy Observatory has successfully withstood simulated tests of noise generated at liftoff, as well as the aerodynamic noise encountered during travel through the atmosphere.

The satellite will scan and map gamma and x-ray sources in order to gather more data on pulsars, quasars and black holes. It will orbit above the obscuring effects of the atmosphere and below the belts of radiation which interfere with stellar radiation observations.

Computer Enhances Photos

The computer technique that has greatly enhanced spacecraft photographs of Mars and Mercury has been extended to photos taken with large telescopes at Mount Palomar and Kitt Peak, revealing significant details in cosmic objects previously unobtainable.

The new technique has increased the detection capabilities of the great telescopes, according to Dr. Halton Arp, astronomer at the Hale Observatories, and Jean Lorre of the Jet Propulsion Laboratory's Image Processing Lab.

In a recent issue of the **Astrophysical Journal**, Arp and Lorre reported that computer image enhancement combined with optical techniques has squeezed more information out of astronomical photos, revealing for the first time "new features in the faint outer regions of galaxies and also . . . faint filaments and nebulous features in areas between galaxies".

Resolution was improved 50 percent by the computer, which removed from the photos some of the effects of Earth's atmospheric turbulence. The use of computers on color plates has brought out compositional differences in parts of galaxies. Applying the techniques to astronomical photographs stems from Arp's efforts (with Lorre's assistance) to push the seeing ability of the great Earth based telescopes.

For pnotographic enhancement, Arp selected three specific cosmic objects having puzzling features that are under investigation. Two of them are groups of galaxies (Stephan's Quintet and Seyfert's Sextet). The third is the jet in the radio galaxy M-87. Arp chose several photographs of each that had been taken with Palomar's 200 inch Hale telescope and a 48 inch Schmidt telescope, and the 158 inch telescope at Kitt Peak.

The enhancement experiments involve scanning the plates with a photoelectric eye which converts the variations in dark and light in the photo plate into numbers that are readable by the computer. The computer can then be told to mathematically manipulate the photo. This phase of the work was done at the Image Processing Laboratory with computers. Photographic techniques were also used to further sharpen the enhancement.

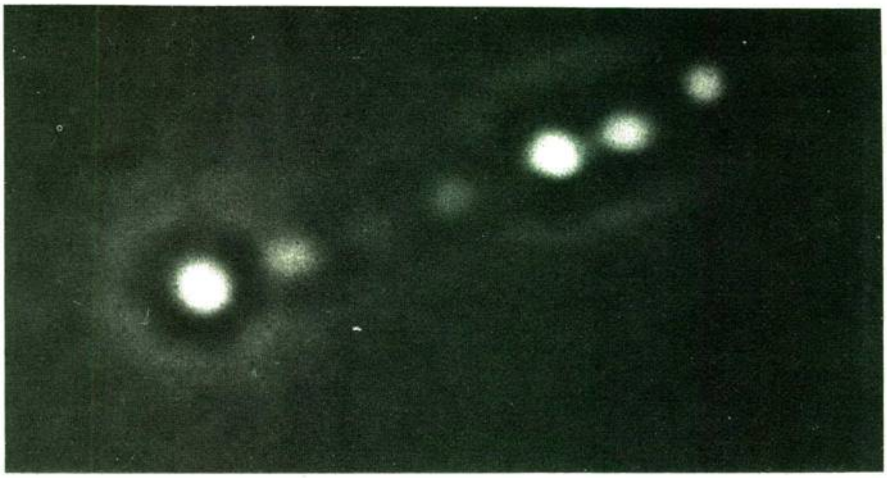
When desired, the computers removed all the stars from an astronomical photograph, leaving only the objects of interest. Undesirable background shading and other inhomogeneities also were filtered out mathematically. In effect, what was left was the faint nebulosity that you could see once you'd removed all the distracting effects.

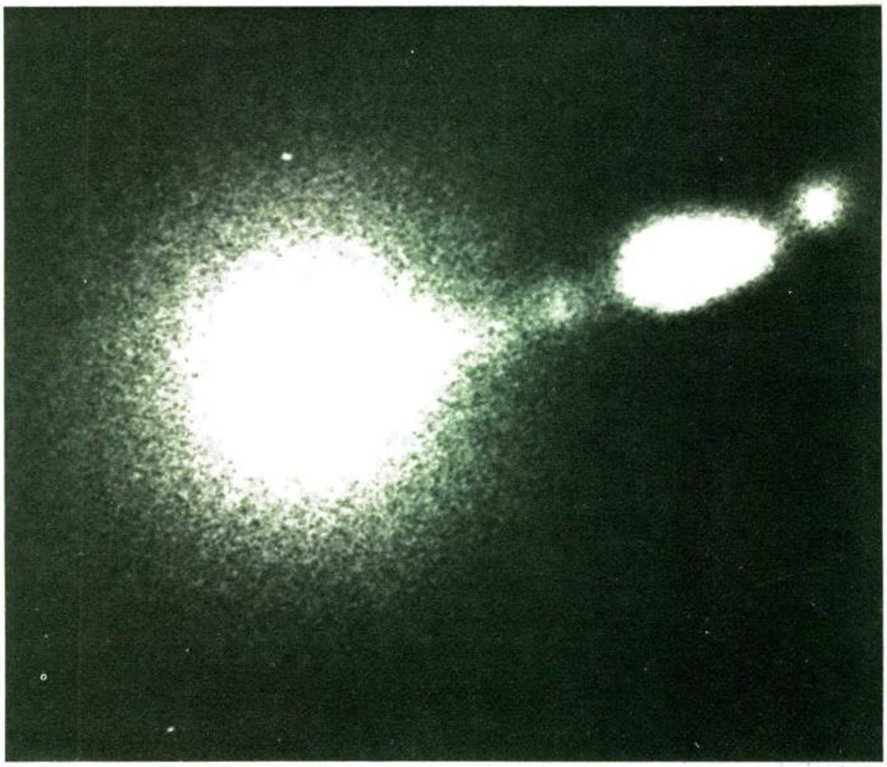
Some of the diffusing effects of Earth's atmosphere were removed by eliminating part of the fuzzy halo effect around stars. This improved resolution by a factor of two.

This particular technique revealed details in the jet of M-87 more clearly than had been observed before: seven luminous condensations stretched out in a virtually straight line.

For the enhancement of extremely subtle differences in the brightness of a cosmic object, photographs were printed with very high contrast. Unfortunately, stepping up the contrast also emphasized very slight blemishes. In such cases, several photographic plates of the same object were superimposed. The blemishes appeared in different locations on different plates, so the superimposition did not build up their intensity. It did, however, build it up for the objects of interest, because they were in the same position

Computer *continued on page 59*





These photographs demonstrate how computer image enhancement brings out hidden phenomena in astronomical photographs. The bottom photo, taken by Dr. Halton Arp with the 200 inch Hale telescope at Mount Palomar, shows a jet emanating from the radio galaxy M-87. At the top is the computer enhanced version of the same photo, revealing seven luminous condensations that may be the result of giant pulsed explosions. Hale Observatories photographs.

Computer *continued from page 58*

on all of the superimposed plates. Then the contrast could be increased to further bring out the subtle variations in the photos.

A variation of this kind of enhancement involved telling the computer to look only at the areas of the photograph where changes in light and dark intensity occurred, and to emphasize those places. The computer ignored flat areas in the picture where there were no variations in tone, but focused on areas where there were gradients in tone. The resulting picture on the computer image screen exaggerated regions of change from dark to light.

Another technique Arp found informative was the use of color in astronomical photographs. A black and white photo was taken of Stephan's Quintet in blue wavelength, and a similar black and white photo was taken in red wavelength. Both photos were "fed" into the computer, and the differences between the red and blue pictures which were due to color were exaggerated.

On a visual display, the computer projected Stephan's Quintet in color. The interiors of the galaxies showed up as red, and the outer extremities were blue.

"It's known that the interiors of galaxies are redder — have more red stars," Arp said. "The outer parts of the galaxies contain young, blue, hot stars. The coloring reveals extended blue tail filaments."

The five galaxies in Stephan's Quintet are known to have markedly different redshifts. According to the conventional viewpoint, this means that some of the galaxies in the quintet are much farther away than others — the greater the redshift, the greater the distance.

However, Arp believes that redshift indicates something other than distance, and that the galaxy members of the quintet are near enough to each other to be interacting.

"That's why," he explained, "it's so important to learn whether this blue tail belongs to the galaxy that appears to be near it."

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Radio Galaxy Potential Largest Radio Source

A new contender for the title of largest known radio galaxy in the universe is 3C 123. At a distance of approximately 10 billion light-years, it is one of the strongest radio sources in space.

The radio source was mapped with the 100 meter (about 328 feet) Effelsberg (West Germany) radio telescope by W. Reich of the Max Planck Institute for Radio Astronomy, and P. Kalberla and J. Neidhofer of Bonn University's Radio Astronomy Institute. The maps revealed several faint sources around 3C 123, in a configuration resembling the number five pattern on dice. In particular, the sources identified by the letters A and D lie in a line on opposite sides of 3C 123, giving the classic double structure observed in many radio galaxies and quasars. Two more sources, lettered E and F, lie in another line either side of 3C 123, almost at right angles to the first pair, completing the dice pattern. "If the sources A to D or E to F are physically related to 3C 123, then the linear extent of the system is larger than any other known radio source," the astronomers reported recently in **Astronomy and Astrophysics.**

The radio galaxy 3C 123 has a high redshift which places it at such a distance that the separation between components A and D would be 32 megaparsecs, and between E and F 42 megaparsecs. (Used by astronomers for measurement of interstellar distances, a megaparsec is equivalent to 19,155,830,550,000,000,000 miles.) Therefore, the distance between A and D would be 640 quintillion miles, and the distance between E and F would be 840 quintillion miles. By contrast, the giant radio galaxy 3C 236 measured at Westerbork in the Netherlands in 1974 has a maximum diameter of about 5.7 megaparsecs, or 120 quintillion miles. Not only is the proposed size of 3C 123 bigger, but its power output (at 21cm) is nearly 100 times that of 3C 236.

Before the staggering size proposed for 3C 123 can be accepted (50 to 60 times the distance between us and the Andromeda galaxy), confirmation is required that sources A and D or E and F are really associated with the central radio galaxy. The German team hopes to establish this with further observations. If all four turn out to be linked with 3C 123, then astronomers will be faced with the still greater puzzle of how 3C 123 had ejected two lots of material at right angles to each other.

Alcock's Nova Resurges

British astronomer George Alcock broke his own world record for visual nova discoveries when he detected a nova in the constellation Vulpecula on Oct. 21, 1976. The discovery was made after a 15 minute search with 15 x 80 binoculars from the backyard of his home near Peterborough, England.

Alcock originally estimated the nova's magnitude at 6.5, but other observers reported it somewhat fainter. That same night, Eugene Harlan at Lick Observatory took a spectrogram with the 24 inch reflector, which indicated the nova was near maximum. Over the next few days the nova faded, but then recovered some of its brightness. On Nov. 2, it underwent an unexpected surge to about magnitude 6.3 — at least 25 percent brighter than at its discovery. Although novae often undergo secondary eruptions, they rarely outshine the initial outburst.

The nova has been identified with a formerly 19th magnitude star; this range of 12.5 magnitudes (100,000 times in brightness) is considerable, but not exceptional. Measurements made by astronomers in Heidelberg, Germany indicated that the gas thrown off in the initial explosion was expanding at about 559 miles per second (900 kilometers per second), which is average for novae. From polarization of the star's light by interstellar material, astronomers at the University of Oregon have estimated that its distance from Earth is nearly 6,000 light-years — meaning that the star actually erupted around 4000 B.C., and its light has been traveling toward us ever since.

After its second blaze of glory on Nov. 2, the nova began to decline rapidly in brightness.

Double Stars Explain Pulsating Stars

The merging of the two members of a double star system may explain why an unusual type of pulsating star has larger than expected mass.

This is the most likely of several explanations examined in a recent issue of the **Astrophysical Journal** by Drs. Leonard Searle and Robert Zinn of the Hale Observatories.

Another interpretation is that the variable stars formed recently — only one billion years ago — whereas the other stars in their parent galaxies formed 10 billion years ago.

While these are the favored explanations, the mystery is far from solved. One key to the riddle is provided by the systems in which the variable stars reside. These stars are found in five of the six extremely low mass galaxies of the dwarf spheroidal type, which are nearby neighbors of our Milky Way galaxy.

Another neighbor of our galaxy, the Small Magellanic Cloud, also contains them. But that galaxy's companion, the Large Magellanic Cloud, does not. So far, astronomers have identified only one variable of this class in our galaxy.

Searle and Zinn obtained observations (with the 200 inch Hale telescope on Mount Palomar) showing that the variables in the Draco dwarf spheroidal galaxy have 1.5 times the mass of the sun — roughly two to three times larger than expected. In other respects, however, the stars are similar to the well-known RR Lyrae and Cepheid variables, which are used as yardsticks to set the scale of the universe. Like these other variables, they pulsate in a regular fashion, keeping time for hundreds of thousands of years. They differ in that they are more luminous than the RR Lyrae variables that have similar periods of pulsation — 4/10 to 1 day.

Searle and Zinn believe that the significance of these unusual stars to astronomy depends on the final interpretation of their origin. If, indeed, they are young, then stars were forming out of gas in the Draco galaxy a billion years ago.

This is contrary to the present theory, which says that small galaxies such as the Draco galaxy are so loosely constructed and have such a small gravitational field that all of the gas should have escaped soon after the galaxy was formed, 10 billion years ago.

On the other hand, if each of the variable stars was once two stars, then their presence in the Draco galaxy is understandable. But their absence in the Large Magellanic Cloud is puzzling.

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Soviets Find Meteor Crater

Based on recent studies, Soviet scientists have indicated the discovery of what appears to be a large and ancient impact crater, 6 miles deep and 400 miles wide. This discovery gives evidence that the bombardment of Earth by large meteors did not end in our planet's earlier years.

The Soviet discovery was described by Dr. Frank Dachille of Pennsylvania State University at the annual meeting of the Meteoritical Society (an international association) in October 1976, at Lehigh University in Bethlehem, Pa.

The area in northern Kazakastan in the Soviet Union is now heavily eroded and filled in. The enormous crater would cover northeastern United States from Boston to Baltimore. It appears to have been formed four billion years after Earth's formation, or around 425 million years ago. According to Dachille, such impacts occur about once very 100 million years.

Dachille used estimated timetables of crater producing impacts on the moon, plus the recent discovery and dating of several large crater remnants on Earth, to approximate the relative frequencies of large and small impacts on this planet.

Older craters have been identified through the discovery that the explosive impacts in which they were formed left telltale rock transformations. Included in this are tiny diamonds, greatly compressed forms of quartz (coesite and stishovite), shatter cones, and minerals known as impactites.

Soviet scientists have suggested that the impact ruptured Earth's crust deep enough to release volcanic outpourings and generate ore deposits such as occurred in the Sudbury Basin of Ontario, Canada (the source of much of the world's nickel).

The huge area in Kazakastan — centered on salty Lake Tengiz, and now referred to as the Ishim Impact Structure — has been attributed to impact because of the seemingly shock-altered quartz formations there.

Employment Rate For Women in Academic Institutions Increasing

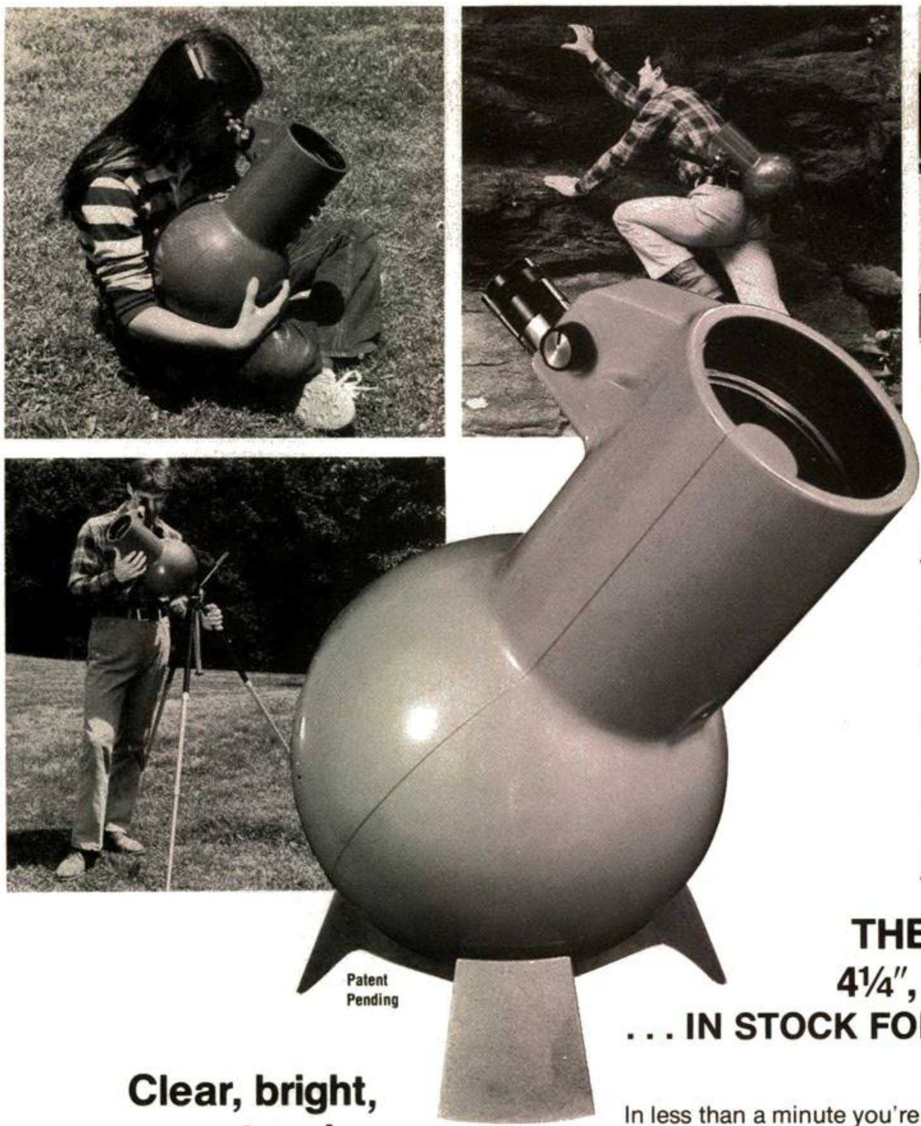
The National Science Foundation has reported that the rate of employment of women scientists and engineers in academic institutions increased six percent as opposed to their male counterparts, who had an increase of two percent.

The report, covering the period from January 1974 to January 1975, was titled "Manpower Resources for Scientific Activities at Universities and Colleges, January 1975". It states that the total employment of all scientists and engineers increased four percent on the university/college level.

The statistics illustrate the active growth period of scientific concerns in the late sixties, the decline in the early seventies, and the mild upsurge in the midseventies. During the 1965-71 period, the number of full-time scientists and engineers increased at an annual rate of 7.7 percent. Between 1971 and 1974, it decreased to 1.5 percent, and then increased by three percent from 1974 to 1975.

The recent surge of women into the scientific academic community may seem overwhelming, but the actual gains are small. Women hold 15 percent of the total full-time science and engineering positions. But even with a six percent increase in employment during 1974-75, women's proportional share of employment actually increased less than one percent. The number of men in the field is so large that the two percent increase in the total overshadows the six percent increase of the women.

Other findings of the report indicate that the largest growth was in three categories (psychologists, mathematicians and social scientists), which accounted for an increase of 105 percent.



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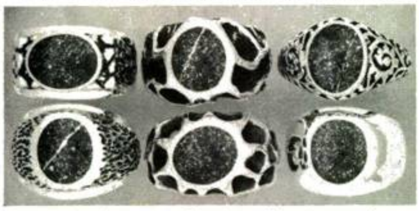

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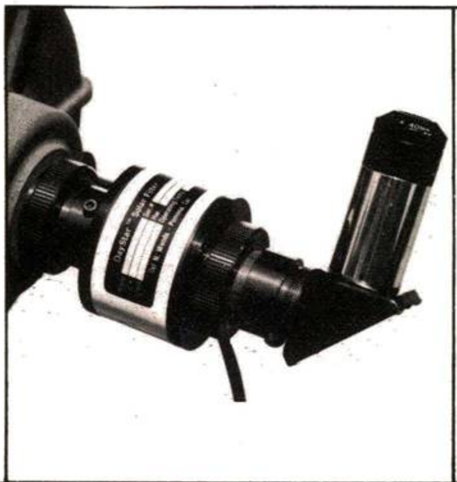

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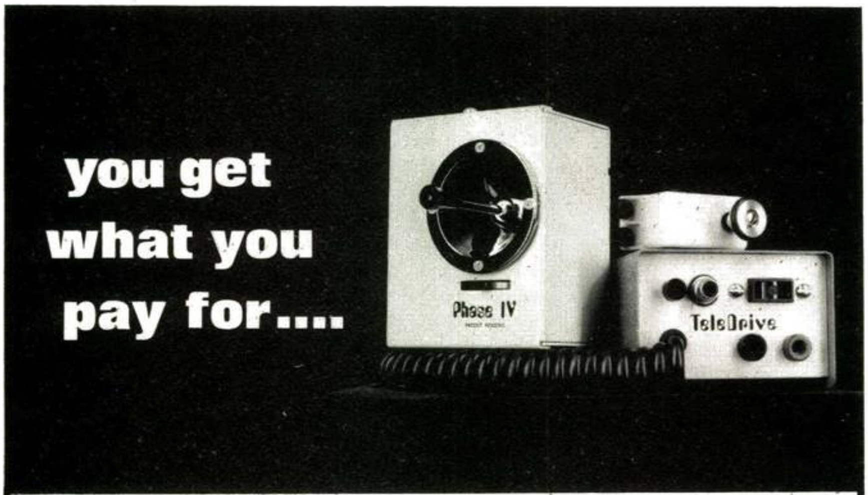

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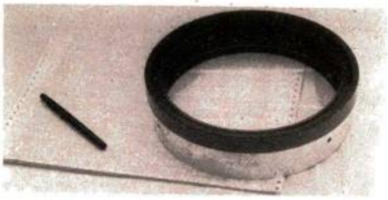

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WANTED — Correspondence with persons throughout the world interested in astronomy. Write José Luis González, Portalegre 13-4ª A, Madrid 19, SPAIN.

WANTED — "The Beauty of the Universe" by Hans Rohr; published in 1972 by Viking Press. All correspondence answered. Write Norman G. Guenther, 2101 Leovey Ln., Midlothian, VA 23113.

WANTED — Biographical information on astronomical/science fiction illustrators. Need names, addresses, birthdates, photos (will return after copying), anecdotes, etc. Write Jon Gustafson, Box 2003-CS, Pullman, WA 99163.

WANTED — Reflector with equatorial mount, clock drive, setting circles, finderscope. Price range: $100.00 to $125.00. Write Michael Harrison, 21 Edith Ave., Saugerties, NY 12477.

WANTED — Persons interested in joining UFO investigational organization in New Jersey. Branch is part of larger national network. Write Don Heatley, c/o Unidentified Phenomena Organization, 32 Herfort Rd., Wayne, NJ 07470.

WANTED — Copy of chapter on UFOs in Air Force Academy's 3rd year physics course book, "Introductory Space Science" (advertised in Astro-Mart last year, but has since disappeared). Please contact Mike Hilber, 2419 Ranch Rd., Mequon, WI 53092. Phone (414) 242-1732.

WANTED — Large binoculars (20 x 80 or larger). Contact Robert Huntley, 10 Summer St., Hyde Park, MA 02136. Phone (617) 364-5634 after 6 p.m.

WANTED — "Dome leveler" to measure 90° in all directions; for tabletop use. Also information on tiltmeter and accessories; where to obtain it; prices, etc. Write Scott Siglin, 1005 Prospect Blvd., Waterloo, IA 50701.

WANTED — Person in or near most any major South American city who would show me the skies; will reciprocate. Write Dorothy Stockton, 1414 Flowerree, Helena, MT 59601.

WANTED — Intellectual companion(s) for serious star watchings in Chicago area or farther. Have poor quality 1" refractor (no tripod), several star charts, and good knowledge of both astronomy and physics. Write M. Underwood, 1215 W. Sherwin, Chicago, IL 60626.

WANTED — Correspondence with young people (17-18) interested in astronomy, extraterrestrial life and communication, science fiction, foreseeable interstellar travel, origin of universe, life and man. Write Thair Witmer, 3261 Plass, Topeka, KS 66611.

WANTED — English edition of "The Catalog of Nearby Stars" (1969) by Wilhelm Gleise. Please quote price. Write Beatrice M. Zimmer, 9495 Arlington Blvd., Apt. #101, Fairfax, VA 22030.

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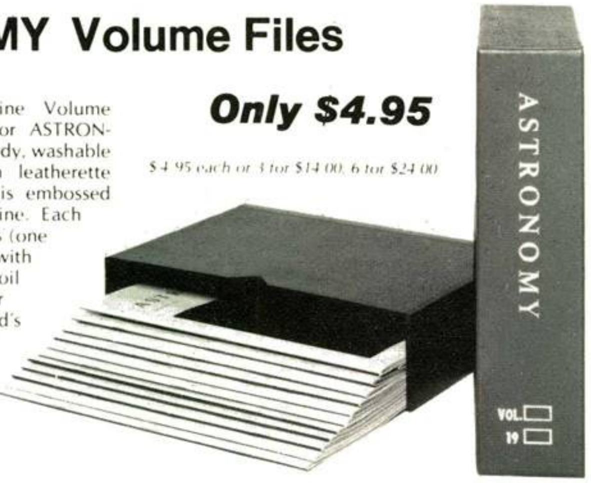

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WANTED — Correspondence with persons interested in finding celestial poles for other planets, and the appearance of the night and day sky. Write Kirk Rutledge, 777 Olive St., Galesburg, IL 61401.

WANTED — Owners of Texas Instruments' SR-56 calculators to swap programs and design some for use in astronomy. Write Dennis Saldusky, Director, Astronomical Society of Fostoria, 211 W. Jackson, Fostoria, OH 44830.

WANTED — Correspondence with persons interested in advancement of computer science, computers in space, minicomputers, advancement in programming, hardware - software. Willing to trade programs. Write Eugene Savage, 1632 Seminole St., Flint, MI 48503.

INFORMATION WANTED — On where to purchase novelty license plates with an astronomical, space program or planetarium theme. Write David A. Artis, 2003 Poplar St., Terre Haute, IN 47803.

INFORMATION WANTED — On location of good observing site within driving distance of Denver. Also contact with any local astronomy group in Denver area. Write Walter Sullivan, 1275 S. Harrison St., Denver, CO 80210.

POSITION WANTED — On planetarium staff. Have B.S. in planetarium astronomy; 2-1/2 years experience in program production, presentation for preschool through adult level audiences. References, resume sent on request. Contact Bob Kelley, 21-335A Lemon Ave., Elmendorf A.F.B., Anchorage, AK 99506. Phone (907) 753-8290.

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ASTRONOMY

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Reader interest in back issues of ASTRONOMY magazine is higher than ever. As a result, our stock of back issues is swiftly dwindling. Below is a guide to ASTRONOMY back issues that are still available. For your convenience it is updated monthly; issues not listed are depleted. **The July 1976 History of American Astronomy issue is specially priced at $3.50 per copy plus postage.**

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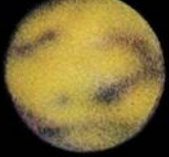
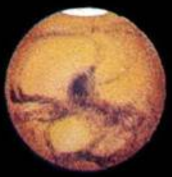
Planet Finder





Ⓒ Ceres

Feb.	1	15
R.A.	12h59m	13h00m
Dec.	+ 9° 04'	+ 10° 12'
Mag.	+ 7.5	+ 7.3

Ⓐ Mercury

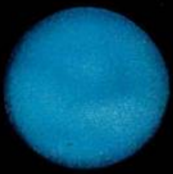
Feb.	1
R.A.	19h19m
Dec.	-21° 49'
Mag.	+ 0.1

Ⓑ Mercury

Feb.	15
R.A.	20h39m
Dec.	-19° 50'
Mag.	-0.1

Ⓜ Mars

Feb.	1	15
R.A.	19h45m	20h30m
Dec.	-22° 09'	-19° 58'
Mag.	+ 1.5	+ 1.5

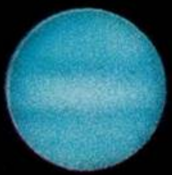


Ⓝ Neptune

Feb.	15
R.A.	16h59m
Dec.	-21° 13'
Mag.	+ 7.7

SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

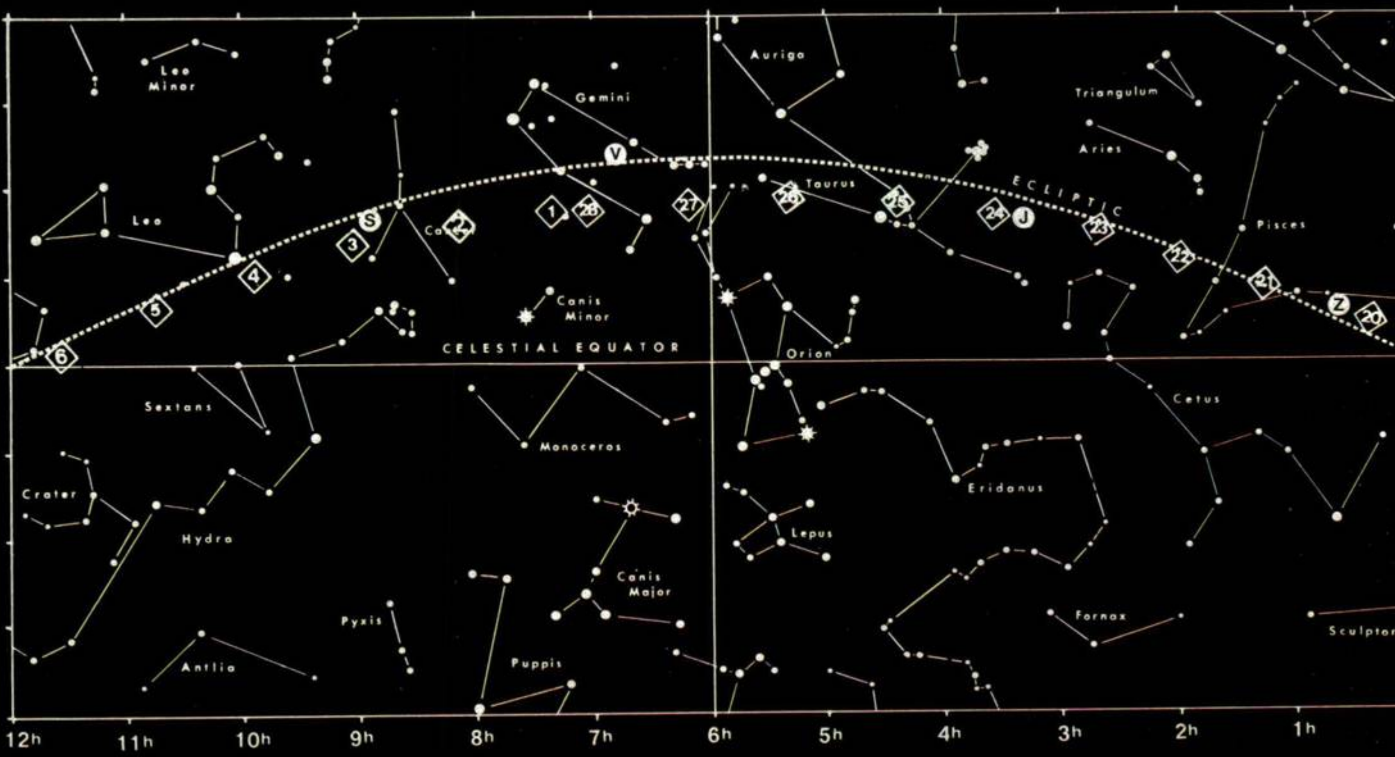


Ⓢ Saturn

Feb.	1	15
R.A.	9h04m	9h00m
Dec.	+ 17° 41'	+ 18° 01'
Mag.	+ 0.0	+ 0.1

Ⓤ Uranus

Feb.	15
R.A.	14h37m
Dec.	-14° 56'
Mag.	+ 5.7



Leo Minor
Leo
Gemini
Auriga
Triangulum
Aries
Pisces
Taurus
ECLIPTIC
Ca
Canis Minor
CELESTIAL EQUATOR
Orion
Cetus
Sextans
Monoceros
Eridanus
Crater
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
V
S
J
Z
1
2
3
4
5
6
20
21
22
23
24
25
26
27
28
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

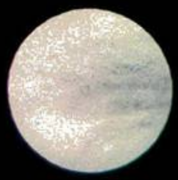
February 1977

Ⓥ Vesta

Feb.	1	15
R.A.	6h55m	6h47m
Dec.	+ 24° 52'	+ 25° 29'
Mag.	+ 7.3	+ 7.4

Ⓙ Jupiter

Feb.	1	15
R.A.	3h18m	3h22m
Dec.	+ 17° 23'	+ 17° 43'
Mag.	-2.0	-1.9



Ⓨ Venus

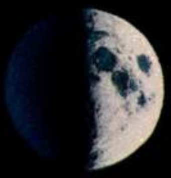
Feb.	1
R.A.	23h57m
Dec.	+ 0° 58'
Mag.	-4.1

Ⓩ Venus

Feb.	15
R.A.	0h39m
Dec.	+ 7° 28'
Mag.	-4.3

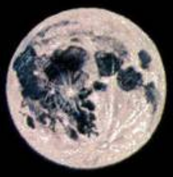
Ⓟ Pluto

Feb.	15
R.A.	13h16m
Dec.	+ 10° 40'
Mag.	+14



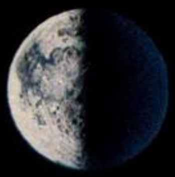
First Quarter

February 25



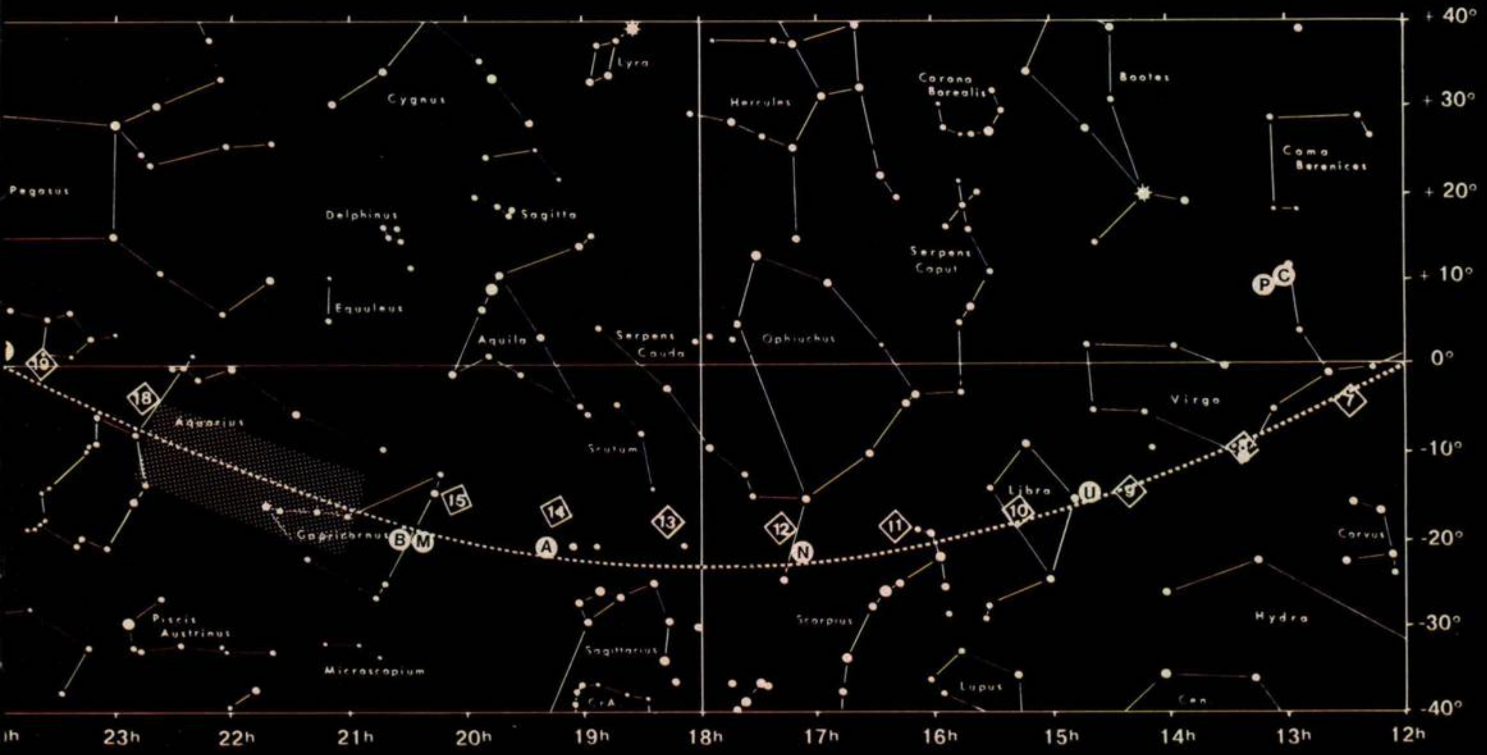
Full Moon

February 3

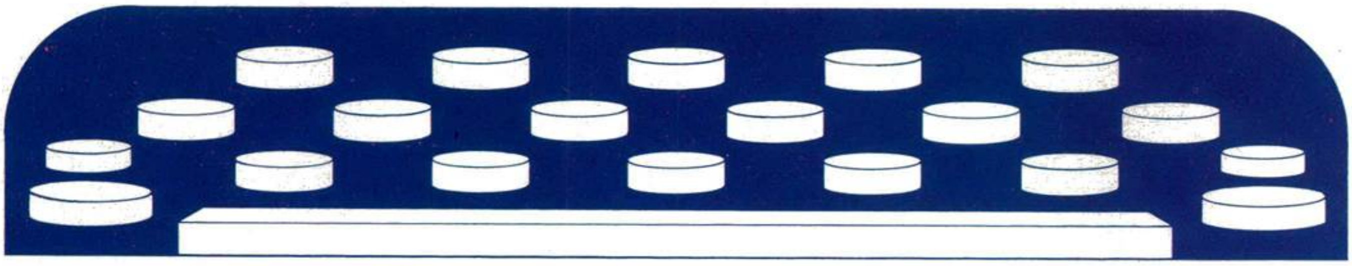


Last Quarter

February 11


Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
Pegasus
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Sagittarius
Scorpius
Hydra
Piscis Austrinus
Microscopium
Lupus
Cen
CrA
19
18
15
14
13
12
11
10
9
8
7
B
M
A
N
U
P
C
+ 40°
+ 30°
+ 20°
+ 10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.



IN FOCUS

Sir / On Jan. 1, 1976, astronomers celebrated the 175th anniversary of the discovery of Ceres. Unfortunately, historical errors concerning the first known asteroid are still being repeated ("Asteroids", ASTRONOMY, June 1976).

Let's set the record straight.

First, Father Guiseppe Piazzi's discovery of Ceres was only one of his many important contributions to astronomy (Dr. Giorgio Abetti's **Dictionary of Scientific Biography**, Vol. X). Second, Piazzi named his discovery Ceres Ferdinandea (an article by Joseph Piazzi in **The Philosophical Magazine**, Vol. XII, 1802; also **Tonight's Asteroids**, November/December 1975). Last, Baron von Zach, not Olbers, recovered Ceres on Dec. 7, 1801 (**Minor Planet Bulletin**, July/September 1975).

JUNE LoGUIRATO
ALPO MINOR PLANETS
SECTION
Clifton, Va.

Sir / I'd like to take exception to one point in an otherwise excellent and helpful article, "Developing B&W Astrofilms", in the September 1976 issue. The table on page 51 lists D-19 developer as "not recommended" for High Contrast Copy film. Actually, D-19 is the only one listed in Kodak's instructions. What's going on here?

DAVID HEALY
Manhasset, N.Y.

Mr. Healy / The author of the article, David Hudgins, feels that D-19 gives too much contrast for astronomical subjects and recommends other developers that produce a softer negative, though still "ultracontrasty" by pictorial standards. Kodak's recommendation applies to the film when used as a document copying film.

Sir / I am building an 8 inch Cassegrain telescope, and have a question. Right now, I have a 4-1/4 inch reflector. Is it possible for me to use my 4-1/4 inch equatorial mount for the 8 inch Cassegrain? The tube is 30 inches long.

DAVID M. HEARN
Saltsburg, Pa.

Mr. Hearn / Without more information about your 4-1/4 inch telescope's mounting, it isn't possible to accurately answer your question. However, very few small telescopes have mountings steady enough to support a telescope weighing two or three times the weight of the original instrument. Hence, we would guess that you will need a new mounting for your larger telescope.

A good telescope mounting should have little or no vibration; in short, if you are ever annoyed by shaking or trembling images, your telescope is inadequately mounted. If the object you're looking at moves when you focus or touch the focus knob, if the wind causes your images to do a little dance, or if a tiny bump on the tube makes repointing your telescope necessary, your telescope's mounting is too weak.

Sir / In reference to a letter from Barry Gordon in the November 1976 issue of ASTRONOMY — how pessimistic! Suggestions are valuable, but I think he's overdoing it a bit — and I object strongly to almost everything he said.

I don't think that printing text over very light photos makes the words illegible, but instead adds extra interest. As for his saying the artwork is "awful" — I'd like to see him do better. The artwork is very enjoyable — especially those paintings showing what things *might* look like, such as "Saturn from Pioneer", "Inside the Orion Nebula", etc. They let you use your imagination a bit. And I'm not sure where he got the idea that the paintings don't fit in with the text. When an article is talking about Venus, and Venusian landscapes are depicted, that's about as close to the text as one can get — isn't it?

His statement that the Eyepiece Impressions are "meaningless blobs and swirls of color" and that they are really "nothing" is as wrong as one can get. If those drawings are meaningless, then so is observing, because throughout the history of astronomy celestial objects have looked about the same as they do in those drawings. I have never heard an observer call any celestial object "meaningless". One just has to be able to appreciate celestial objects for what they are, and to imagine what mystery and vastness they really hold.

Without imagination, one cannot participate in astronomy, for imagination and astronomy go together.

DALE LIGHTFOOT
Tulsa, Okla.

Sir / In "Look North for Aurorae" (October 1976), Richard Berry mentions various methods of looking for aurorae. One method not mentioned involves the use of an "everyday" AM radio. No elaborate equipment is necessary.

Whenever conditions for aurorae are present, AM radio stations that can be heard from long distances at night — from the north, on skywave propagation (that is, stations received by being bounced off the ionosphere as opposed to groundwave or "line-of-sight" receptions) — will be weak or completely inaudible. The best way to use this method is to select one or two strong radio stations to the north which are at least 300 miles away from your location (to rule out groundwave reception), and get to know their frequency so you can check on them every night. On nights when these stations are weak or nonextistent there is a good chance of a visual aurora. This method will not work every time, however, since aurorae will affect radio first and may not become strong enough to become visible. However, since aurorae always affect AM (and sometimes shortwave) signals in this fashion, it is a waste of time to look for an aurora on nights when stations from the far north are coming in loud and clear.

HARRY J. HAYES
Gouldsboro, Pa.

Ooops!

Here are a few errors in recent issues that our readers have pointed out to us:

October 1976, page 21 — the third photograph should say "Cerro Colorado, Mexico". Cerro Colorado means "red hill" in Spanish.

October 1976, page 28 — captions were omitted in the painting showing "perfect optical systems". From left to right, the images should be labeled: "Unobstructed Reflector", "Refractor", "Schmidt-Cassegrain", and "Newtonian Reflector".

November 1976, page 32 — in the double star table, Beta and Zeta Lyrae were switched.

December 1976, in the Star Dome map — the hours of right ascension were reversed. 3 hours is correct, but you should switch 2 and 4, and 1 and 5.

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DEC	- 10.41

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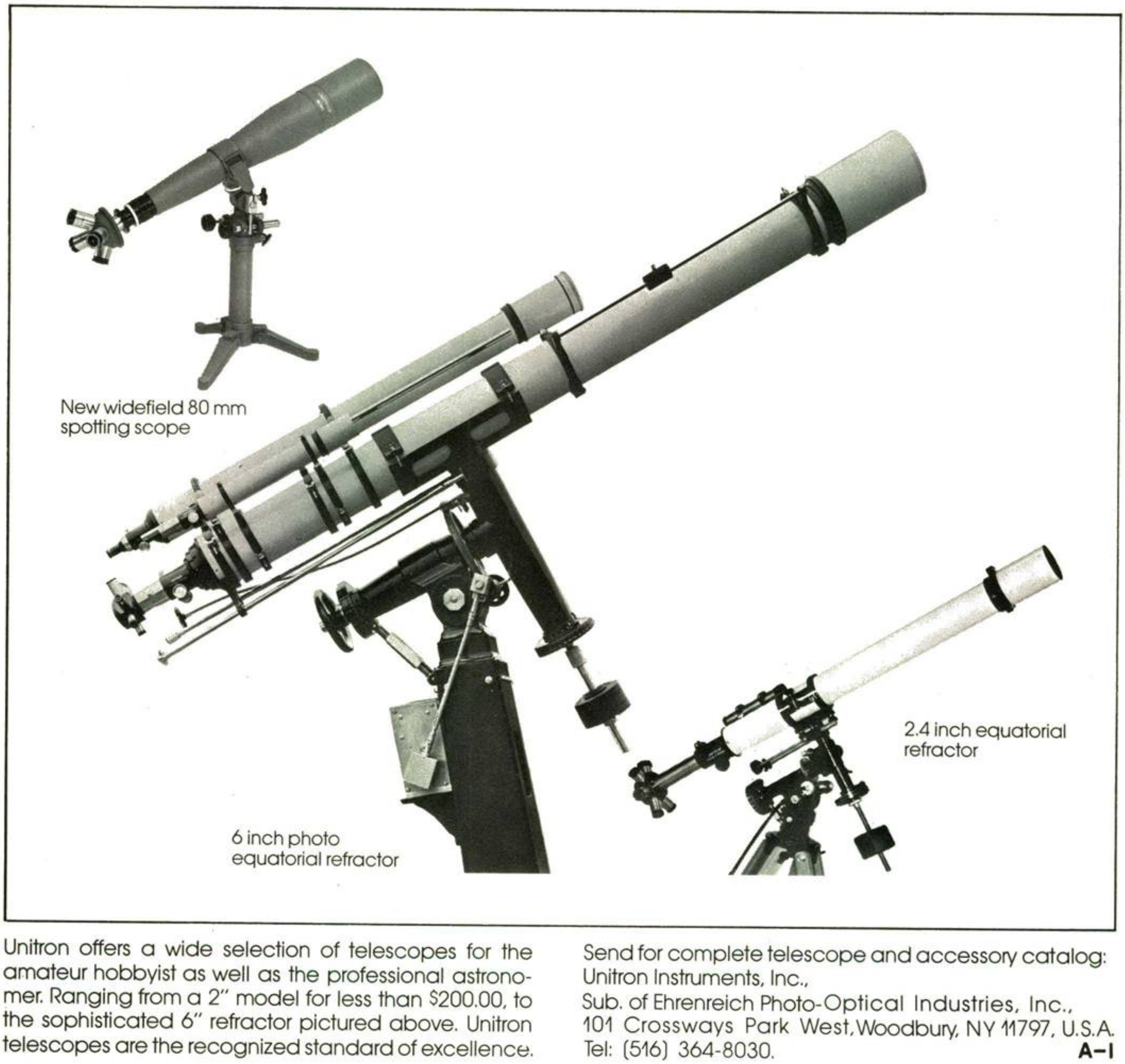

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STAR DOME

FEBRUARY

by

James Mullaney and Henry J. Phillips

Stargazers who enjoy myths and legends about the major constellation figures have undoubtedly noticed other groups that have no stories. In between the characters from classical Greek and Roman mythology lie constellations depicting scientific instruments, or birds and animals without mythological associations. For the most part, these latter groups contain no bright stars or distinct patterns and are quite uninteresting to the naked eye — hardly seeming to merit the name "constellation" at all. Where did these groups come from, and why did their inventors choose to depict the objects they did?

Until the 17th century, there were about 50 recognized constellations. The definitive list was considered to be that contained in the **Almagest** of Ptolemy that dates from the second century A.D. This atlas of star positions carefully charts, by constellation, 1,022 stars visible from the latitude of Alexandria, Egypt. Ptolomy's work remained the standard text throughout Europe's Dark Ages.

Then came the Renaissance, and voyages of adventure and discovery. Imagine the surprise of 15th and 16th century navigators, when their ships brought them into southern latitudes where new stars appeared!

Obviously, the new (or, more accurately, rediscovered) stars had to be organized into constellations of their own, so that navigators could learn the stars more easily and be able to "get their bearings" during those ocean voyages. In 1603, Johann Bayer, in his famous atlas the **Uranometria**, did just that: 12 new star groups appeared in the charts of this atlas.

Bayer himself did not invent these new constellations, but attributed them to the navigators Amerigo Vespucci, Andreas Corsalius, Petrus Medinensis and Petrus Theodorus, with most of the credit for formation going to Theodorus. But because Bayer was the first to publish the new groups, and because the **Uranometria** was widely praised and accepted, the new constellations became known as Bayer's. All 12 are still recognized today; most of them are located near the sky's south pole. They include Apus the bird of paradise, Chamaeleon the chameleon, Dorado the goldfish, Grus the crane, Hydrus the water snake, Indus the Indian, Musca the fly, Pavo the peacock, Phoenix the firebird, Triangulum Australe the southern triangle, Tucana the toucan, and Volans the flying fish.

As we can see from this list, the inventors of the Bayer groups were less interested in immortalizing more old mythological figures than in commemorating some of the discoveries made in the New World. With the exception of Triangulum Australe, the constellations depicted new animals and birds — along with a "new" race of men.

Once Bayer's atlas, including these new groups, was published, there was no stopping other cartographers who were determined to introduce their own constellations. Some of these men genuinely wished to fill up gaps between the old figures; others were apparently interested in nothing more than personal aggrandizement. Among the former group we can list Bartschius, Johannes Hevelius and Nicholas LaCaille.

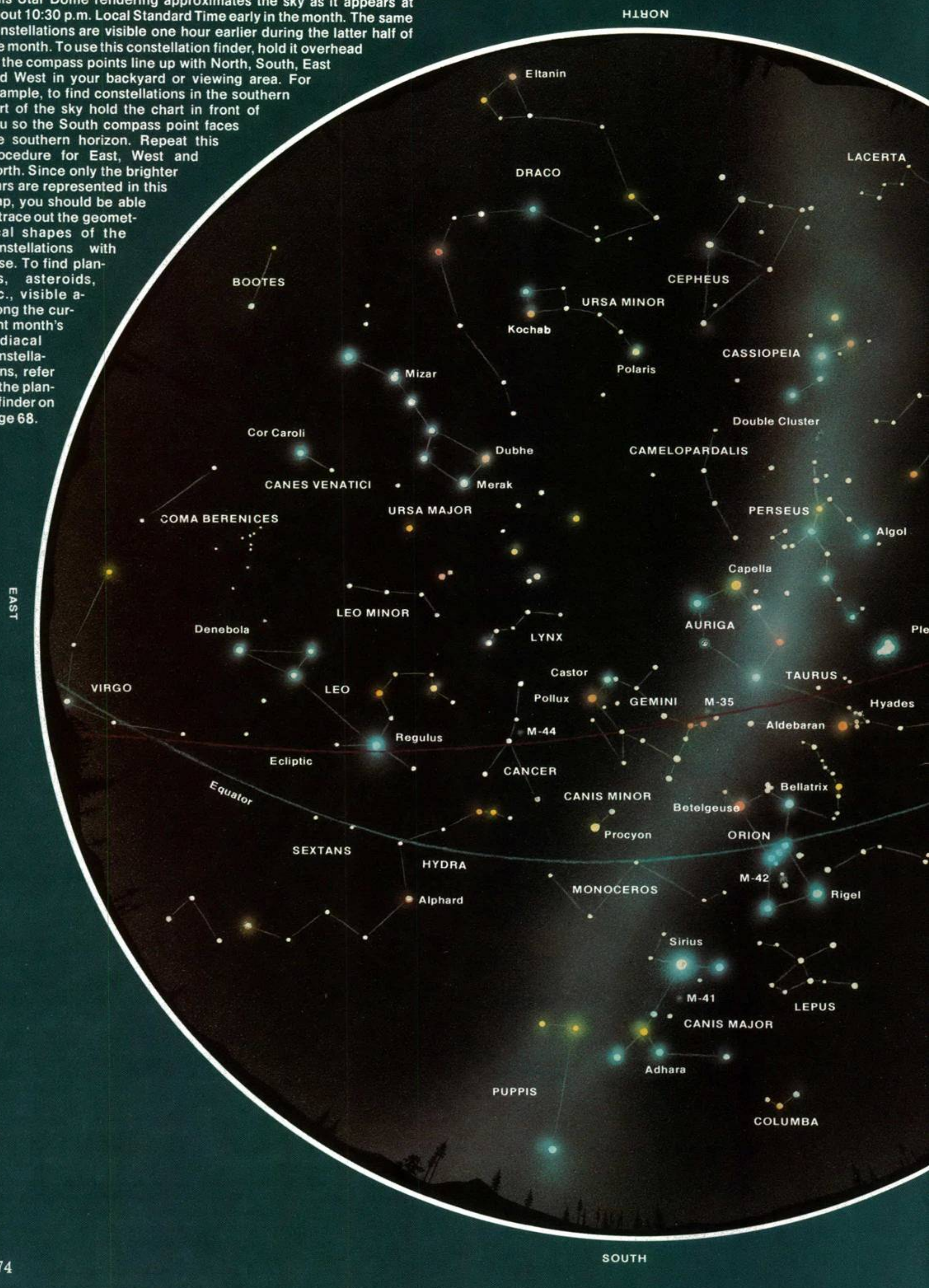
Bartschius is generally thought to have invented Camelopardalis the giraffe and Monoceros the unicorn (both found on this month's Star Dome map) for his 1624 **Planisphaerium Stellatum**. However, like Bayer, he was responsible only for their publication, and not their invention. Bartschius returned to mythology (in a sense) for these groups; both animals were probably regarded as legendary, although this turned out not to be the case with the giraffe.

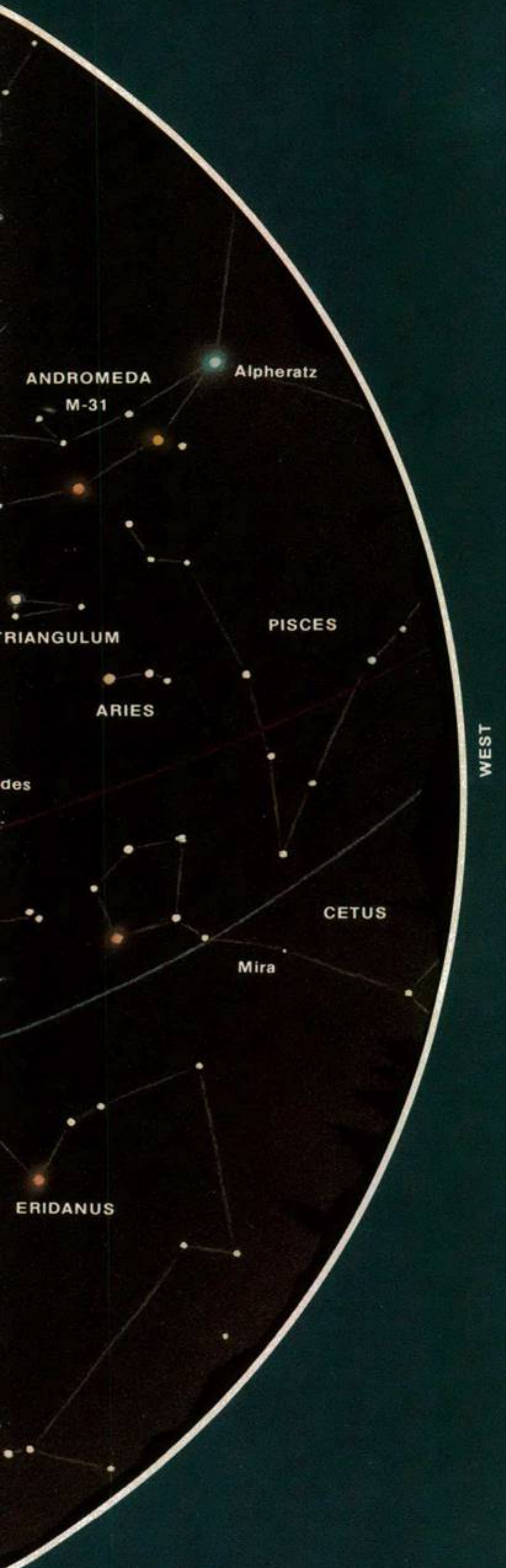
In 1690, Hevelius' **Prodromus Astronomiae** (published posthumously) incorporated several more new constellations. Seven of these have survived; we know them today as Canes Venatici the hunting dogs, Lacerta the lizard, Leo Minor the little lion, Lynx the lynx, Scutum the shield, Sextans the sextant, and Vulpecula the fox. More than other astronomers of his day, Hevelius had a wry sense of humor, and many of his constellation figures have amusingly droll or bewildered expressions. Especially memorable is the atlas's frontispiece — an elaborate allegorical drawing, depicting Hevelius presenting his new groups to the muse of astronomy. For the most part, Hevelius placed his constellations where they were needed; most of them happen to contain notable or important deep sky objects.

The final inventor of surviving "modern" constellations was the French astronomer LaCaille, who introduced 14 new groups into the sky in 1752. By that date, the "Age of Reason" had reached France, and the ancient gods and myths were considered passé. Man and his accomplishments were to be glorified above all else. LaCaille's groups reflect this belief, as all but one represent "the principal implements of the sciences and fine arts". Most of LaCaille's original constellation names have been shortened considerably, and it is interesting to note the titles he gave them (modern shortened versions in italics): Antlia Pneumatica (*Antlia*, air pump); Caelum (graving tool); Circinus (artist's compass); Fornax Chemica (*Fornax*, chemical furnace); Horologium Oscillatorium (*Horologium*, pendulum clock); Mons Mensae (*Mensa*, table mountain); Microscopium (microscope); Norma et Regula (*Norma*, level and square); Octans Hadleianus (*Octans*, Hadley's octant); Equuleus Pictoris (*Pictor*, painter's easel); Pyxis Nautica (*Pyxis*, mariner's compass); Reticulum Rhomboidalis (*Reticulum*, rhomboidal net); L'Atelier du Sculpteur (*Sculptor*, sculptor's studio); Telescopium (telescope).

Table Mountain, the exception to LaCaille's preoccupation with instruments, was the site from which LaCaille made his observations of the southern sky. Whatever else may be said of these constellations, they have one thing in common: All are virtually invisible. Only three (Circinus, Pictor and Reticulum) contain stars as bright as third magnitude; the rest are placed

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 68.


NORTH
Eltanin
LACERTA
DRACO
BOOTES
CEPHEUS
URSA MINOR
Kochab
CASSIOPEIA
Polaris
Mizar
Double Cluster
Cor Caroli
Dubhe
CAMELOPARDALIS
CANES VENATICI
Merak
URSA MAJOR
PERSEUS
COMA BERENICES
Algol
Capella
EAST
LEO MINOR
AURIGA
Denebola
LYNX
Ple
Castor
TAURUS
VIRGO
LEO
Pollux
GEMINI
M-35
Hyades
M-44
Aldebaran
Regulus
Ecliptic
CANCER
Bellatrix
Equator
CANIS MINOR
Betelgeuse
Procyon
ORION
SEXTANS
HYDRA
M-42
MONOCEROS
Rigel
Alphard
Sirius
M-41
LEPUS
CANIS MAJOR
Adhara
PUPPIS
COLUMBA
SOUTH



in blank areas of the sky. Antlia, especially, is particularly notable for its utter lack of anything interesting, both to the naked eye and the telescope. And yet, these constellations have survived as officially recognized star groups.

LaCaille's instruments indicate the depths to which constellation-inventing had fallen by 1752. Other astronomers invented constellations that happily have disappeared — including the electric machine, the printing office and the weather balloon! Generally these groups were either placed in totally starless regions of the sky, or were formed out of stars ruthlessly ripped from existing constellations. An example of the latter is Robur Carolinum (Charles' oak), which scientist Edmund Halley formed in 1679 to commemorate the oak tree in which Charles II of England had hidden from Cromwell 28 years earlier. This is, perhaps, no more silly than some constellations that other scientists invented in praise of their patrons. But Halley formed Robur Carolinum from most of the brightest stars in the classic constellation Argo Navis (today split into Carina, Puppis and Vela), thereby completely ruining that figure. Halley's oak has since passed into oblivion.

Other attempts at introducing new constellations have failed, and the scientists, cartographers and fame-seekers who put them in the sky have all missed this particular form of immortality. In any case, the matter was settled once and for all in 1930, when the International Astronomical Union assigned the official constellation boundaries along lines of right ascension or declination. The astronomers had little or no interest in the old mythological figures, and although they did try to include as many stars in a constellation as it had had for the ancients, the main impetus for establishing the borders was to provide handy designations for the unwieldy number of variable stars.

Now that boundaries have been delineated, a constellation — in the strictest sense — is nothing more than a designated area of the sky, and LaCaille's air pump is no less valid a constellation than Orion. The casual stargazer must make his own decision as to whether this is a good or a bad state of affairs; there will always be some of us who will prefer to see the old classic figures making their annual rounds.

Close-Up

Monoceros/Canis Minor Region

"Inconspicuous to the naked eye, but rich in groups and clusters" was Webb's introduction to the constellation Monoceros the unicorn. This region is, indeed, crammed with interesting objects for binocular and telescope users — proving (as Barns pointed out) " . . . that the more famous constellations have no monopoly of stellar marvels. This one presents varied beauties and complexities. Even random sweeping charms."

One of the great deep sky observers of the past generation was Leland Copeland of California, who paid special attention to this area of the sky. It would be difficult to improve on his delightful invitation to its exploration: "To find Monoceros is easy if one looks for the great triangle formed by three first magnitude stars, Procyon, Betelgeuse and Sirius. This bounds the most interesting part of the constellation. An old stanza, saved for posterity by Admiral Smyth, praises this resplendent delta:

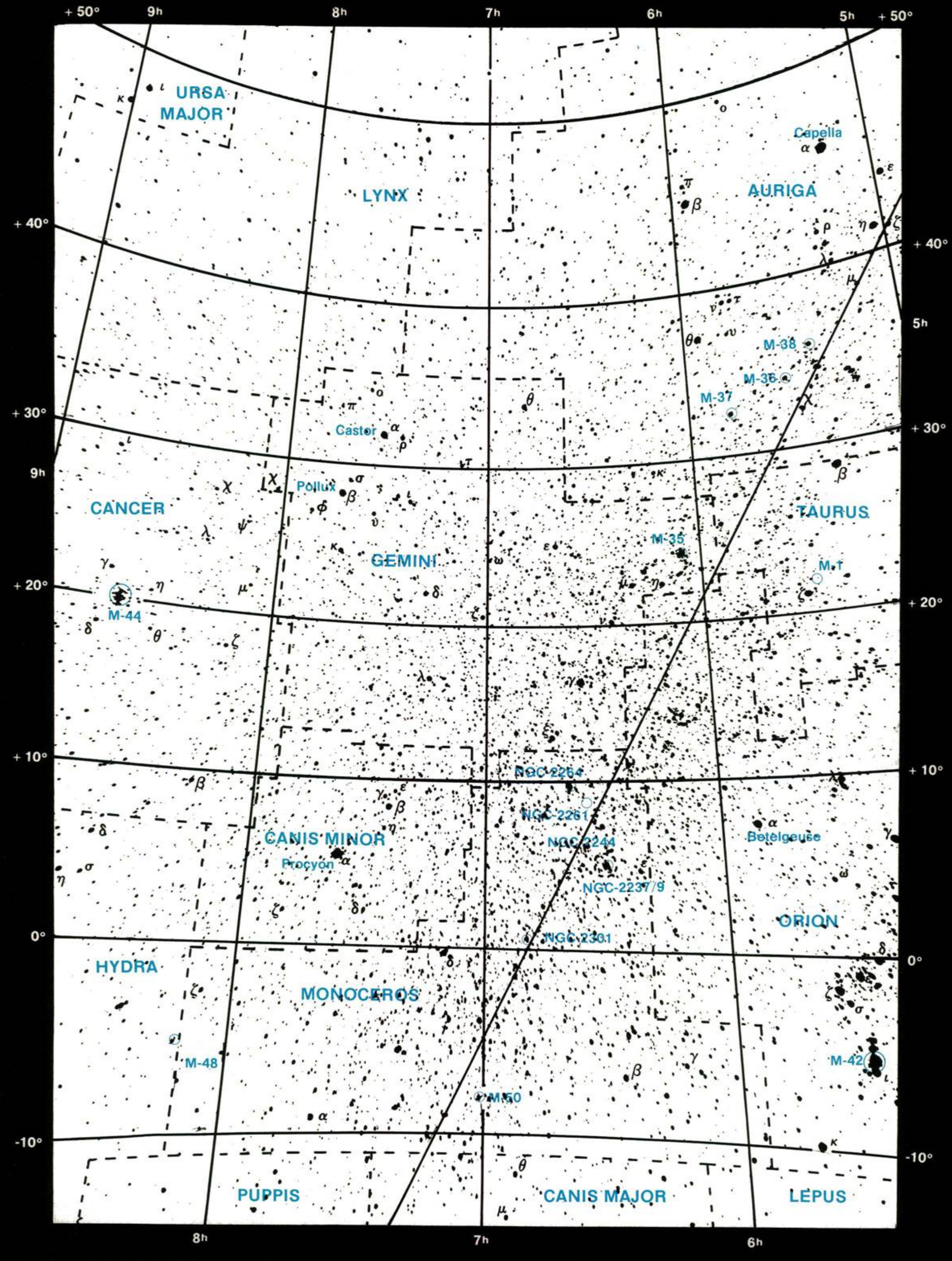
'Let Procyon join with Betelgeuse,
And pass a line afar,
To reach the point where
Sirius glows —
The most conspicuous star;
Then will the eye delighted view
A figure fine and vast,
Its span is equilateral,
Triangular its cast.'

Behind this starry frame is a beautiful hidden world, awaiting the owner of a small telescope who is willing to search in a stellar wasteland for the treasures of Monoceros."

Careful sweeping of this region of the winter Milky Way with a good pair of binoculars or a richest field telescope (RFT) will show many striking groups and configurations of stars not even hinted at by most star atlases. A good example is the loose open cluster surrounding the star 10 Monocerotis. Webb described the scene: "Sixth (magnitude) pale yellow, the lucida of an elegant group, visible with the naked eye." Officially labeled NGC-2232, this easy object is omitted in most atlases. Another is the magnificent low power field surrounding the gold and blue double star Epsilon (ϵ) Monocerotis.

In our enthusiastic plaudits about the star fields of Monoceros, we mustn't forget that another constellation shares this month's region with the unicorn. This is Canis Minor, the lesser dog — faithful companion to Canis Major and Orion. Barns called this a "compact asterism" and mentioned "many worthies to look up".

The first of these is zero magnitude Procyon, described in detail below. Another is the star Beta, which Barns described as "Prince of a resplendent court of suns of high and low degree, finely placed for leisurely study". Aside from a number of faint double and multiple stars, Canis Minor has little else to offer the visual observer;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+10°
NGC-2264
+10°
β
γ
ε
β
NGC-2261
δ
η
α
CANIS MINOR
NGC-2244
Betelgeuse
γ
Procyon
α
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η
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NGC-2237/9
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ORION
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NGC-2301
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CANIS MAJOR
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6h

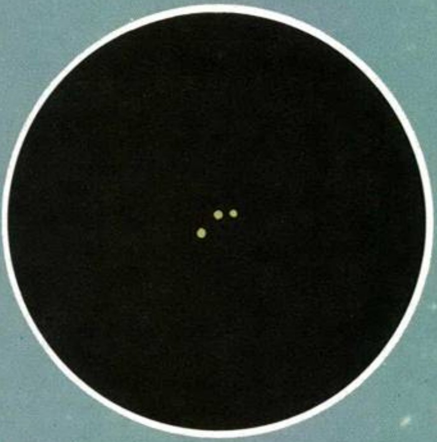
Photograph by Brad Wallis and Robert Provin
Map by Richard Berry

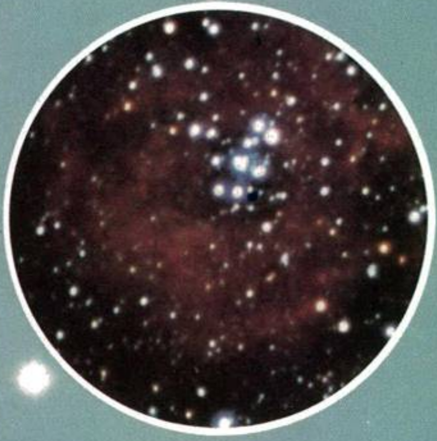
in fact, it might be completely passed over were it not for Procyon.

Procyon

Procyon — Alpha (α) Canis Minoris — seems greatly overshadowed by Betelgeuse and Sirius, its partners in the great equilateral triangle mentioned above. It is a yellowish white F type sun whose tint is described as "pale topaz" by Barns. It is also one of our nearest stellar neighbors in space — a mere 11 light-years from Earth!

Beta Monocerotis





NGC-2237-9 and NGC-2244

Above left: Beta Monocerotis has been called the most beautiful triple star in the sky, and a view through any telescope does much to reinforce this impression. Our drawing shows Beta as seen through a five inch Schmidt-Cassegrain at 250 power; the field of view is about 10 minutes of arc. Below left: This is a photograph of the Rosette nebula (NGC-2237-9) and its associated cluster, NGC-2244. The nebula itself is difficult to see; only long exposure photos can reveal it in all its glory. This is a 75 minute exposure on Fujichrome R-100 film, made through a 200mm lens at f/3.5. Drawings by James Mullaney; photograph by David Healy.

Procyon's claim to fame was related by Webb: "A fine yellow star, to which Schaeberle added the *comes*, long predicted by Bessel, with the Lick 36 inch (refractor) in 1896." The *comes*, or companion, is a white dwarf sun, much like the famed companion to Sirius. The presence of both these dwarfs was deduced from their perturbing gravitational tugging on their primaries before they were actually seen.

Procyon B appears as an 11th magnitude glimmer of light nestled within the glare of its blazing primary at an average distance of only four seconds of arc. Its orbital period is only 40 years, so more than two complete circuits have been made since its visual discovery.

Can a six or eight inch instrument reveal this tiny object today? Since a 36 inch telescope was needed to discover it, most observers have apparently been discouraged from searching for it. We should, however, remember the truth of Sir William Herschel's famous dictum: "When an object is once discovered by a superior power, an inferior one will suffice to see it afterwards."

This object is much more difficult to glimpse than is the companion to Sirius, so the instrument you are using should be able to show Sirius B before you try for Procyon B. Excellent diffraction-limited optics and nights of extreme image steadiness are a must for success. Make your attempt when Procyon is on or very near the meridian. Here is a challenge to sky, instrument and observer second to none . . . anyone care to meet it?

If, like most of us, you are a small telescope user, Procyon still has something to offer. It has a number of faint optical attendants, and the vicinity is rich in small pairs and triplets. Thus it makes a fine "warmup" object before exploring the outposts of Monoceros.

Beta (β) Monocerotis

A real jewel in the Monoceros treasure chest is a star that many consider to be the finest triple in the sky. This is fourth magnitude Beta Monocerotis, visible to the unaided eye about a third of the way from Sirius to Betelgeuse. Surprisingly, many astronomy enthusiasts have never seen this beautiful object.

Sometimes labeled 11 Monocerotis on atlases and observing lists, Beta consists of 4.7, 5.2 and 5.6 magnitude yellowish suns in a slender triangle whose greatest extent is 10 seconds of arc. This system was discovered by Herschel in 1781, and is sometimes referred to as "Herschel's Wonder Star". He considered this trio "one of the most beautiful sights in the heavens" — and so it is! Pickering included this system in his prestigious list of the sky's 60 finest objects, published in 1917. Strangely, Barns called it double rather than triple in his classic work.

Even a three inch refractor at 90 power gives a thrilling view when seeing conditions are good. In four inch and larger instruments the scene greeting the eye is breathtaking, as our drawing can only indicate. Beta is tight enough to remain striking even in big observatory telescopes with their great image spread.

The three components' relative positions have remained essentially unchanged since their discovery; yet it seems obvious that the stars are physically associated with one another. As Webb expressed it, "striking appearance of connection, yet very stationary". He went on to list the colors of the stars in order of brightness as white, yellowish white, and gray or bluish. Others have reported the 4.7

Selected Objects — Monoceros/Canis Minor Region

Object	Type	Mag.	Size/Sep.	R.A. (1950)	Dec.
MONOCEROS					
ϵ(Epsilon)	★2	4.5, 6.5	13"	6^h21^m	+04°37'
*β(Beta)	★3	4.7, 5.2, 5.6	7", 3"	6^h26^m	−07°00'
*NGC-2244	OC	6.2	40'	6^h30^m	+04°54'
*NGC-2237-9	DN	—	64' x 61'	6^h30^m	+04°40'
*NGC-2261	DN	Var.	2' (v)	6^h36^m	+08°46'
*NGC-2264	OC/DN	4.7	30'/60' x 30'	6^h38^m	+09°57'
*S Monocerotis	★2	4.7(v), 8.0	3"	6^h38^m	+09°57'
NGC-2301	OC	5.8	15'	6^h49^m	+00°31'
RV Monocerotis	V:132^d	6.8-8.3	—	6^h56^m	+06°14'
*M-50	OC	6.9	16'	7^h00^m	−08°16'
CANIS MINOR					
*α(Alpha)	★2	0.3, 10.8	4"	7^h37^m	+05°21'

*Detailed in Close-Up

★2 = Double Star
★3 = Triple Star
OC = Open Cluster
DN = Diffuse Nebula
V:#^{d} Variable Star, period (days)
Mag. = Magnitude
Sep. = Separation

magnitude member as having an orange tint.

Beta lies some 470 light-years from us amid the glitter of the winter Milky Way. Should you look at nothing else in this month's region, take time the next clear night to check out this gorgeous triple star.

M-50

The main attraction of Monoceros to many observers is its profusion of sparkling open clusters. One of the best is M-50, situated about a third of the way from Sirius to Procyon. Although readily visible as a misty patch in finders and binoculars, the observer must sweep for it since there are no naked eye stars nearby.

This intermediate-rich splash of suns has the combined luster of a seventh magnitude star, and boasts some 100 members in an area half the apparent size of the full moon. Its brightest beacons hover near ninth magnitude.

At low magnification in telescopes four to eight inches in aperture, M-50 is a stunning sight on a dark night. Even the **New General Catalog**, with its terse form of notation, calls it "remarkable". Bernhard, Bennett and Rice, in their **New Handbook of the Heavens**, described it as "a bright cluster, superb, with red star". Barns also mentioned this star: "Fine cluster. Blood-ruby star in center." Finally, Webb called M-50 a "brilliant cluster, straggling . . . to 30 minutes, containing a red star . . . in a superb neighborhood."

Well worth braving a frigid winter night to see, M-50 beckons our attention from across 2,600 light-years of interstellar space.

NGC-2237-9/2244

Working our way northwest of M-50, we survey the first of several "nebulous looking" clusters. This is NGC-2237-9/2244, better known as the Rosette nebula (and its associated cluster). It can be picked up by sweeping with low power about two degrees east of the double star Epsilon Monocerotis (labeled 8 in some atlases).

The Rosette is a huge stellar incubator in which astronomers believe new stars are being born. NGC-2244 is the aforementioned cluster — a splendid glow of bright and faint stars surrounding the giant yellow sixth magnitude sun, 12 Monocerotis. Together, they have been seen without optical aid.

NGC-2244 is loose and irregular, and contains perhaps two dozen stars of various magnitudes in an area 40 minutes of arc in extent. Webb called it "beautiful" and mentioned that the fainter stars run in rays. Barns commented, "Pearl cluster. Magnitude six star almost involved in naked eye sunburst." Note that none of these commentaries say anything about the nebula itself, providing a clue to its elusiveness. The multiple NGC designation 2237-9 refers to the various segments of the nebulosity, which takes the form of a large ring.

Often seen in color photos, the Rosette glows brightly in the red light of hydrogen, but is extremely faint visually — much like the famous Horsehead nebula in nearby Orion. Like most diffuse nebulae, no definite magnitude can be assigned due to its extended nature. This one measures twice the apparent size of our full moon (61 by 64 minutes)!

As a result, most telescopic fields cannot begin to encompass the Rosette in one view. Low power and wide fields are more important than aperture in glimpsing its ghostly cast. A 4-1/4 inch RFT with 15 power and a 3-1/2 degree field is ideal for attempting such observations.

NGC-2244 lies near the central "hole" of the nebular ring, and is a good starting place for viewing the Rosette. Using averted vision on a dark (moonless) transparent night, you should be able to see the brighter parts of the nebulosity encircling the cluster. Again, an all-at-once view will require more than one degree of field.

Copeland said, "A little west and north of NGC-2244 nestles a beautiful, very small delta of stars, a delightful object I call Trigon, which has seemingly been overlooked by almost all observers. Some of us will take special possession of this miniature marvel of three relatively bright stars close together." This object is Struve 939, a wide trio of eighth and ninth magnitude stars.

The Rosette itself is more than 3,000 light-years distant.

NGC-2264/S Monocerotis

Continuing northward in the sky, some four degrees above the Rosette complex, is another often pictured nebula which is seldom searched for by the astronomy enthusiast. Here, again, we find a cluster associated with nebulosity — but with a unique twist. The action this time is centered around S (15) Monocerotis — double/variable star!

This object consists of a 4.7 magnitude primary (an irregular pulsating sun of uncertain period) and an eighth magnitude companion only three seconds of arc distant. There is also an 11th magnitude star 17 seconds away. Thus, Barns called this object a "striking triple . . . very colorful". Webb listed these colors as green, blue and orange, respectively.

Like the Rosette and its associated cluster, NGC-2264 has a dual nature. It is a modest cluster of about 20 stars scattered over a 30 minute field, including S Monocerotis. With an integrated magnitude of 4.7, this group is visible to the unaided eye on a dark night. NGC-2264 is also designated as a diffuse nebula; in fact, this is the Cone nebula, famous from observatory photos. Its size is listed as 60 by 30 minutes in extent; again no total magnitude has been determined. The Cone appears as a tapered shaft of bright nebulosity bounded by dark structures of obscuring dust and gas.

Interestingly, Webb described S Monocerotis, but said nothing about the cluster or nebula. Others mentioned the group of stars, but not the Cone itself. Although a difficult object, it is well worth the search in six inch or larger instruments.

Here, then, in one setting of the telescope, we have the rare opportunity to see *five* classes of celestial objects: double (or triple) star, variable star, open cluster, bright diffuse nebula and dark nebula! Surely this unusual gathering deserves a visit on the next clear night.

NGC-2261

We conclude our survey of this month's region with an even greater challenge for the visual observer. This is Hubble's amazing Variable nebula, located a degree south of S Monocerotis near the southern border of the Cone nebulosity. It lies almost exactly midway between S and 13 Monocerotis.

This tiny smudge of light varies both in surface brightness and apparent angular size, averaging around two minutes of arc. Its nucleus is occupied by the irregular variable star R Monocerotis, which attains a peak magnitude of only 9.5. It is therefore absent from all but the most detailed charts and atlases.

Variations in the nebula are apparently coupled to the variable star itself. These fluctuations are quite rapid, often perceptible within a single day. The underlying cause for all of this is shrouded in mystery, but again it may have something to do with stellar birth.

Hubble's Variable nebula isn't often observed, and we may be missing important clues to its true nature. Readers with telescopes 10 inches or more in aperture would do well to monitor this strange and fascinating object.

As we have seen, the Monoceros/Canis Minor region has something for everyone — binocular and RFT users, as well as owners of observatory sized instruments. Within the glimmer of its starry framework lurks a buried treasure for all to enjoy. Here is sheer enjoyment in its purest sense! And, as Copeland summed it up, "Although celestial glories such as these were not especially made for Man, they will enrich leisure hours."

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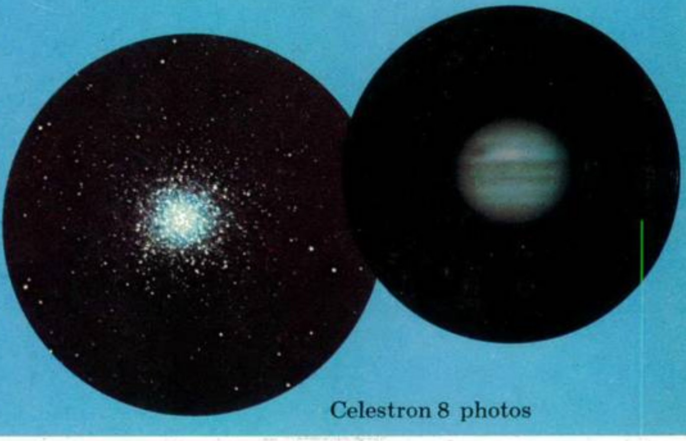

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